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SEISMIC FORCES ACTING ON THE EMBEDDED PART OF THE STRUCTURE

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SUMMARY

Fundamental characteristics of seismic forces acting on the embedded part of the structure were investigated using 2-dimensional dynamic FEM models. Structures embedded in two layered soil were analized with predominant period of the structure and the shear wave velocity of the surface layer as parameters. From the obtained results, simplified static method to evaluate the design shear force of the embedded part, considering the effect of dynamic soil-structure interaction, was proposed. Calculations by the proposed method were in good agreement with the response values.

INTRODUCTION

Seismic forces acting on the embedded part of the structure are 1)shear force from the structure above the ground level, 2)inertia force of the embedded part and 3)the force due to the dynamic soil pressure. Shear force on the embedded part of the structure can be obtained from the sum of these forces, but the information on the quantities of the above mentioned forces affecting the shear force on the embedded part have not yet been clarified because of the complication of their behaviour. Therefore, in order to make rational evaluation of the design seismic force on the embedded part of the structure, it is important to investigate the fundamental characteristics of the forces through soil-structure interaction problems.

In this paper, earthquake response analyses by 2-dimensinal FEM are carried out with rather a simplified soil-structure models, and fundamental characteristics of the seismic force (shear force) acting on the embedded part of the structure are studied. Also, on the basis of the obtained results, rational scheme to evaluate the design seismic force of the embedded part, using maximum response displacement of the free field, is proposed.

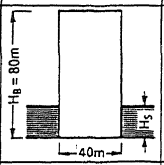
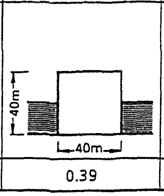
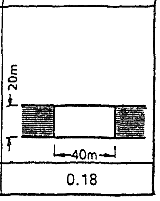
FUNDAMENTAL CHARACTERISTICS OF FORCES ON THE EMBEDDED PART

ANALYSIS As shown in Table-1, three types of structures, tall, comparatively low and fully embedded structures, which have the same plan of 40x40m, and the same embedded depth of 20m are assumed. For the soil, two layered system consisting of surface layer and rock continuum are considered. Shear wave velocity of the rock continuum is set to 400 m/s and that of the surface layer are assumed 100, 200 and 400 m/s, respectively.

2-dimensional FEM models with energy transmitting boundary are used in the analyses. The structures are modelled by isotropic elastic solid elements, and in order to account for 3-dimensional effects and preventing reflecting wave effects, viscous boundaries are located along the planar surfaces and at the bottom of the soil models. By combining 3 types of structures and 3 types of soil conditions, total 9 cases are analyzed in this study. Table-2 shows the material constants of the structures and the soils, and Fig.-1 shows the typical example of the FEM model used in the analyses.

Control earthquake motion for the analyses, which is shown in Fig.-2, is generated artificially from the design shear coefficient spectrum used in Japan as a target spectrum, and is defined as an incident wave at the bottom of each structures. By the use of one-dimensional amplification theroy, control earthquake motion is then deconvolved to determine input motions at the bottom of the entire model.

Table-1 Structures for the analyses

Case	A	B	C
Model			
T_B(sec)	1.2	0.39	0.18

T_B : Natural period of Structure Plan (40m × 40m)

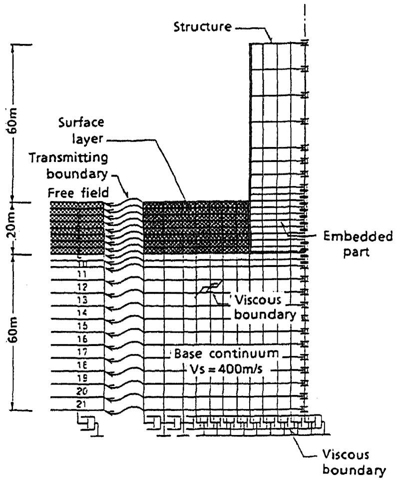


Fig.-1 FEM model for analyses (A-2)

Table-2 Material constants

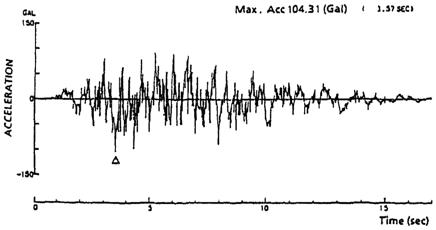
(Soil)

Surface layer	Vs	Ts	ν	ρ	h
1	100	0.8	0.45	1.8	5.0
2	200	0.4			
3	400	0.2			
Base layer	400	—	0.45	1.8	5.0

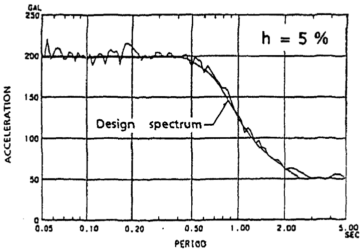
(Structure)

	Vs	ν	ρ	h
Above the ground	500	0.45	0.5	5.0
Embedded part			0.75	

Vs : Equivalent shear wave velocity (m/sec)
Ts : Natural period of surface stratum (sec) ($4H_S/V_S$)
ν : Poisson's ratio
ρ : Weight per unit volume (t/m³)
h : Damping coefficient (%)



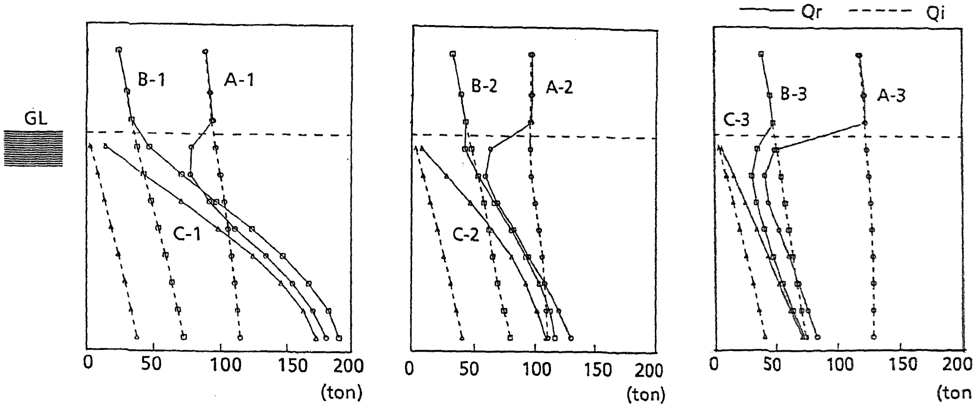
(a) Time history wave



(b) Response acceleration spectrum

Fig.-2 Input earthquake motion

RESULTS Fig.-3 shows the comparison between the distribution of maximum response shear force Qr and maximum shear force Qi due only to inertia force acting on the embedded part of the structures, for the above 9 cases. From these results, it is evident that for the same soil layer, the effect of the difference of the structures appear remarkably near the surface, while in the deeper region, the maximum response shear forces Qr become nearly equal. Also, Qr tends to increase as the surface layer becomes softer.



(a) Vs = 100m/s (b) Vs = 200m/s (c) Vs = 400m/s

Fig.-3 Comparison between maximum response shear force Qr and maximum shear force Qi due to inertia force

As seismic forces acting on the embedded part of the structure can be illustrated as shown in Fig.-4, the response shear forces Qr in the deeper region of the embedded part are said to be governed by the dynamic earth pressure.

Fig.-5 shows the comparison of time history response waves between Qi and the force due to the dynamic earth pressure P, in the case A-2 and C-2. In the case of tall structure, A-2, where the predominant period of the structure Tb is greater than that of the surface layer Ts, P acts in the opposite direction to Qi to decrease response shear force. While in the case of the fully embedded structure, C-2, Tb is smaller than Ts, and P acts in the same direction to Qi like a load, to increase shear force of the embedded part.

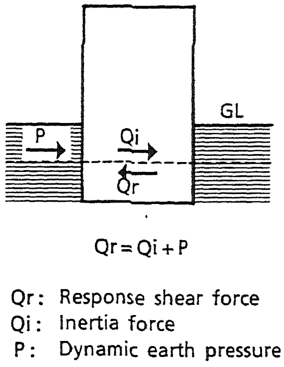


Fig.-4 Relation of forces acting on the embedded part

Fig.-6 shows the distribution of shear force Qr, shear force due to inertia force Qi, and the force due to dynamic earth pressure P at the time when Qr reaches the maximum value. In the case of tall structure, A-2, Qi is greater than P, where as in the case of fully embedded structure, C-2, P is greater than Qi.

Fig.-7 shows the distribution of Qr, Qi and P for the tall structure (A-2) at the time when Q_B reaches the maximum value. Dynamic earth pressure can be seen to act opposite to the inertia force and at this time the response shear force Qr is comparatively small.

The results of earthquake response analyses indicate that maximum shear force Qr of the embedded part varies mainly according to the shear wave velocity of the surface soil layer and the predominant period of the structure. Qr can be classified into following three groups:

(a) Qr increases in the soil.(P acts as a load)

(b) Qr decreases near the surface and increases in the deeper region.

(c) Qr decreases in the soil and is less than Qi. (P acts as a resistance to the structure)

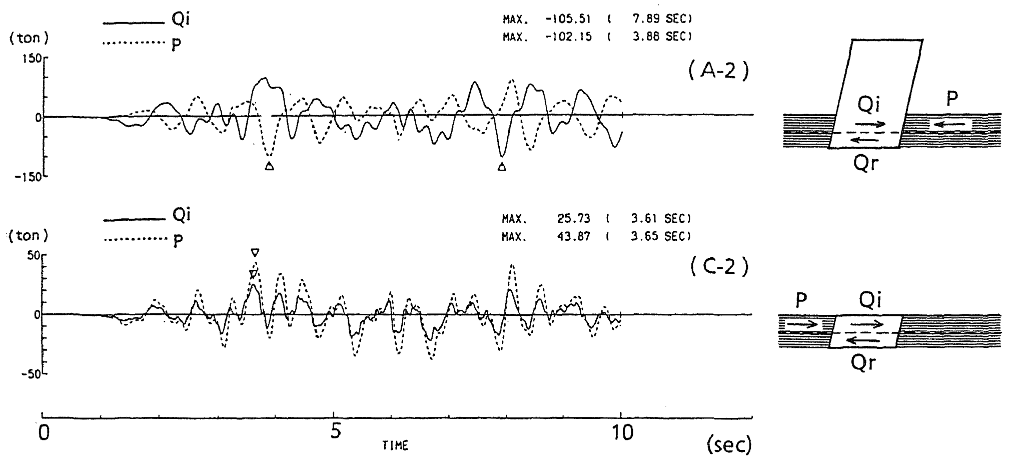


Fig.-5 Comparison of time history response waves between Qi and P

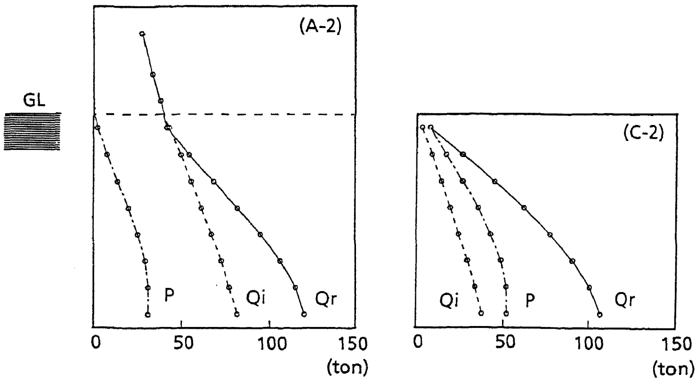


Fig.-6 Distribution of Qr, Qi and P at the time when Qr reaches the maximum value

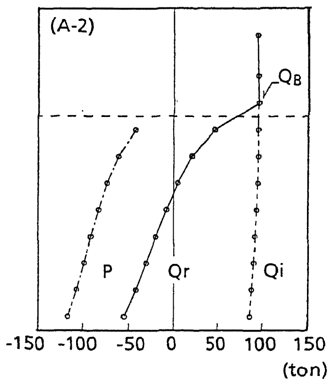


Fig.-7 Distribution of Qr, Qi and P at the time when Q_B reaches the maximum value

In order to evaluate design seismic force Qr of the embedded part without the aid of dynamic response analysis, static values for Qi and P must be assumed from the fact that Qr = Qi + P. Qi can be obtained from code specified values such as a function of predominant period of the structure, but since dynamic earth pressure P is deeply related to soil-structure interaction, it might be difficult to evaluate standard values. However, adequate conservative values are needed in the design, so only the above case (a) and (b), where P acts as a load, should be considered. In these cases, it will be rational to consider envelope values of Qi and Qr as shown in Fig.-8 for design shear force instead of assuming P directly.

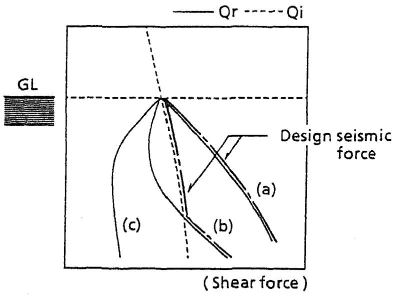


Fig.-8 Pattern of shear force Qr and design scheme

SIMPLIFIED METHOD TO EVALUATE DESIGN SHEAR FORCE

Equation of motion of the embedded part of the structure by Sub-structure method is given by

$$M\ddot{U}+(K_B+K_S)U=K_SU^*+Q_B \qquad (1)$$

where, M :Mass matrix of the embedded part of the structure
K_B :Stiffness matrix of the embedded part of the structure
K_S :Impedance matrix of the soil
K_SU^* :Driving force
U^* :Input motion
Q_B :Force from the structure above the ground level
U :Displacement of the embedded part

In the simplified method, equation (1) is expressed in statical form. That is, K_S is evaluated statically, U^* is evaluated as the maximum relative response displacement of the free field and Q_B as base shear force. Therefore the displacement of the embedded part of the structure can be expressed as

$$U=(K_SU^*+Q_B+F)/(K_B+K_S) \qquad (2)$$

where, F : Inertia force = $-M\ddot{U}$

This method is so called "Response Displacement Method", and although inertia force F in equation (2) is usually ignored, effect of inertia force is taken into account in the following studies.

By using this method, forces acting on the embedded part of the structure were calculated for the case A-2, B-2 and C-2. Analytical model is shown in Fig.-9, and equivalent shear stiffness of the structure, stiffness of the surface soil obtained from static FEM analysis, and base shear force when Qr reaches the maximum value, are used for K_B, K_S, and Q_B.

Fig.-10 shows the comparison of Qr, Qi and P between the above method and the response analyses. The results of the simplified method coincide fairly well with the response values showing the effectiveness of this proposed method.

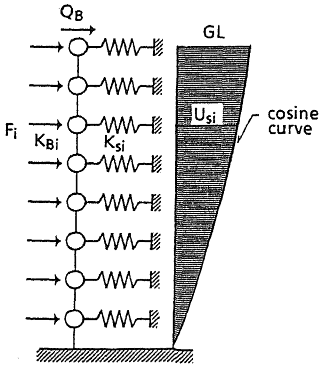


Fig.-9 Simplified analysis model

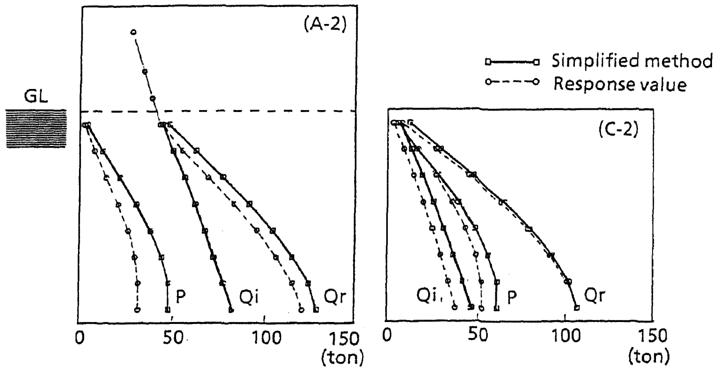
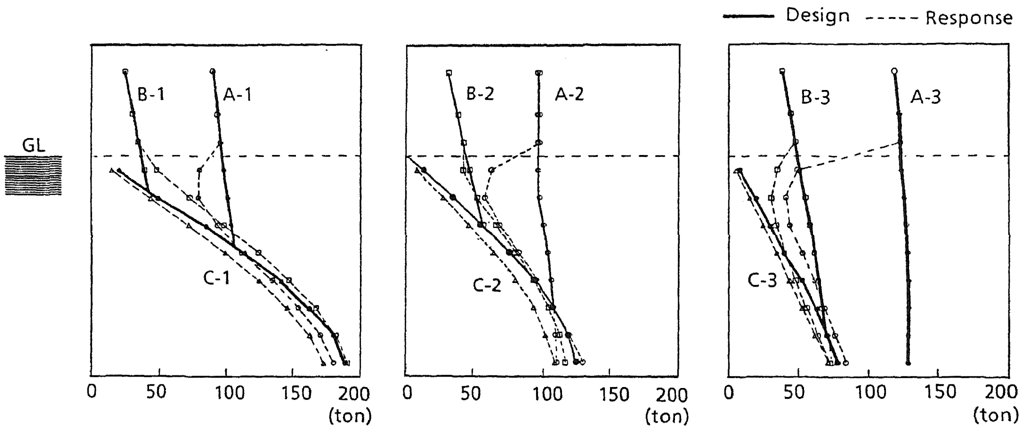


Fig.-10 Comparison between simplified method and response analysis

In applying this simplified method to evaluate the design shear force on the embedded part, displacement of free field U*, inertia force of the embedded part Qi and base shear force Q_B are needed. It is possible to assume displacement U* and inertia force Qi from maximum response values or design codes, but for the base shear force Q_B, it is evident from the results of the previous section that to adopt maximum values would give too conservative values in some cases. One method to overcome this problem is to apply the fact that Qr in the deeper region of the embedded part becomes nearly equal, and ignore the base shear force Q_B. In order not to underestimate response values by this method, some coefficient will be multiplied to give adequate results.

Fig.-11 shows the results of this simplified method with the coefficient 1.2 for the case A-2, B-2 and C-2. Good agreement can be seen between the simplified method and the response values, suggesting that this proposed method would be a practical way to evaluate design shear force of the embedded part of the structure. In order to confirm its efficiency, further case studies, such as the effect of embedded depth, non-linearlity of the soil, method to evaluate static soil stiffness etc. are needed.



(a) Vs = 100m/s (b) Vs = 200m/s (c) Vs = 400m/s

Fig.-11 Comparison between maximum response shear force and proposed design shear force

CONCLUSION

From the analysis of embedded structures, characteristics of forces acting on the embedded part can be summerized as follows;

1) Dynamic earth pressure has a great effect on the shear force.
2) In the case where inertia force is large, the dynamic earth pressure resists to the motion of the structure. Whereas in the case where inertia force is small, the dynamic earth pressure acts as a load.
3) For the same soil layer, the response shear force becomes nearly equal in the deeper region of the embedded part, irrespective of the structure.

Based on the above results, simplified static method to evaluate the design shear force considering the effect of dynamic soil-structure interaction was proposed. Calculation by the proposed method was in good agreement with the response values.

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