VIBRATIONAL PROPERTY AND EARTHQUAKE RESPONSE OF TALL BUILDING SUPPORTED WITH CAISSON OR PILE

by

Tatsuo Tajime (1)
Sadaichi Terada (2)
Toshio Mochizuki (3)

SYNOPSIS

The purpose of this reseach is to study the action of earthquake to building, passing through various type of foundation and soft upper layer, and to pursue the constructional possibilities of tall building on soft upper layer.

Summarizing experimental results, the damping constant pertaining to model supported with caisson or pile are far greater than model settled on base stratum, and displacement response by forced vibration to model supported with pile on soft upper layer where natural period is below 0.14 second, is small, whereas models supported with caisson or settled on base stratum are greater and almost alike.

INTRODUCTION

Recently, regulations pertaining to restriction of building height have been revised in Japan due to the necessity of accommodating more building space in the populated cities. But unfortunately, since majority of such cities are located on soft upper layer, it is necessary to utilize caisson or pile foundation to ensure necessary stability of such building.

This research to obtain necessary factor pertaining to action of earthquake passing through various type of foundations and soft upper layer, will serve to determine the possibilities of constructing higher building on such ground.

MODEL AND METHOD OF EXPERIMENT

The building under study is considered to be 100 meter above ground level, 10 meter underground and steel construction. Understructure for building (A) and (B) are made respectively with pile and caisson supported foundation driven through soft upper layer which is 30 meter in depth and for comparative study, building (C) that settles directly on base stratum at 10 meter depth of soft upper layer and building (D) excluding soft upper layer described in building (C) were adopted.

Model of this building are scaled to be 1/100 in length and mass, 1/6 in time, and settled on artificial soft upper layer located in steel box. In this case, relative properties of building, soft upper layer and foundation are essential and the analogy of these relationship are prerequisite but it is actually quite difficult to perform such analogy as far as the soft upper layer is concerned.

(1) Dr. Eng., Prof., Tokyo Met. Univ., Japan.
(2) Asst., Ditto.
(3) Graduate student., Ditto.

In this experiment, mixture of sand, plaster and water in a constant ratio is utilized instead of actual upper soft layer. The tendency of such mixture causes gradual hardening and strengthening which enables the performance of this experiment every 24 hours continuously for about a week period and the most favorable conditions are selected from derived data. Model, shaking table and type of foundations adopted in this experiment are shown in Fig. I. Foam rubber are located on both internal side of the steel box to prevent possible wave reflection from it.

Motion is recorded on smoked paper attached on drum at 4 points as described in Fig. I. Shaking table is mechanized to perform sine motion immediately from static state by operating a cratch.

VIBRATIONAL PROPERTY

Natural period and damping constant of the model used are calculated from the records of free vibration and are shown in Fig. 2. In reference to Fig. 2. it is noted that the natural periods are from 0.47 to 0.51 second and in general, the value decreases as the artificial soft upper layer harden and the natural period of the model on pile foundation is comparatively longer than the model on caisson foundation. In the case of model (C), natural periods are almost constant and does not vary with the hardening of upper soft layer

The approximate value of damping constant for model (A), (B), (C) and (D) are respectively 0.076, 0.059, 0.017 and 0.015. The relation between damping constant and hardness of soft upper layer and the reason of its decrease in value during the period of 24 hours through 48 hours following the preparation of mixture is not presently clarified.

Vibrational properties of artificial soft upper layer are derived from the response record of forced vibrations. This dynamic response are plotted on Fig. 3 and vibrational properties such as coefficient of soil reaction, damping constant and rigidity calculated from it is drawn in Fig. 4. Natural period are reduced from 0.36 to 0.13 second or more with the elapse of time. The response curve is similar to what Mr. Kanai and Mr. Nakagawa had obtained in their field experiment, wide when it is soft and becomes narrow as it stiffen.

Resonance magnification ratio increases its value as artificial soft upper layer harden and this is considerd to be explainable by taking the difference of damping constant into consideration. Natural period and damping constant are decreased as time elapse and consequently rigidity is greatly increased as indicated in Fig. 4.

Since the approximate natural period of building and soft upper layer are respectively 3 and 0.8 second, analogical condition in this experiment is performed after the elapse of 72 hours following the preparation of artificial soft upper layer since it will constitute similar ratio.

TRANSIENT VIBRATION SUBJECTED TO SHAKING MOTION

Forced vibration was initiated at the shaking table to produce sine wave with a period covering from 0.13 thru 0.8 second. Modifying the date gained to have a constant amplitude shaking motion, relative displacement from building top to ground floor and base stratum is observed from the intial and successive wave.

In reference to Fig. 5, maximum displacement amplitude ratio between a and a_o at the second wave produced by various period of sine type shaking is graduated on vertical axis and elapse time after mixture of artificial soft upper layer was prepared, on horizontal axis.

The value for maximum displ cement amplitude ratio of the model (A) is large when artificial soft upper layer is soft but decreases gradually as it harden and finally gives a minimum value in comparison with the three other types of foundation. It is noted by comparison of Fig. 3 and 5 that maximum amplitude ratio enlarges as the natural period between model and artificial soft upper layer becomes closer.

Maximum amplitude ratio of caisson supported model (B) is not always governed by soft upper layer properties and maintain a constant values. Since the rigidity of caisson is high, vibrational force enters into the model through caisson and artificial soft upper layer.

In the case of (C) and (D), maximum amplitude are similar to (B).

Since the actual interrelationship between building, foundation and soft upper layer is realized in this experiment after t e elapse of 72 hours following the preparation of mixture, this permits a detailed examination of actual effect of earthquake on building.

Maximum displacement amplitude ratio between a and a_o obtained from the second wave from the beginning is graduated on the vertical axis and vibratingperiod of shaking table, on the horizontal axis in Fig. 6.

Response curve of the model (A) have two peaks correlated to its first and second natural period, and have a similar maximum displacement amplitude ratio. Since the second natural period of the model (A) is close to the natural per: of artificial soft upper layer, response at this period is excited and enlar; This provides necessary factor to acknowledge the importance of resonance pr at the second natural period as well as the first natural period.

Response curve of the model (B) is similar in type to the model (A) but a higher value in the vicinity of the second natural period than the first n period and naturally, the maximum displacement amplitude ratio is greater th model (A) and on the contrary, smaller than the model (C) or (D).

Model (C) and (D) indicates a similar response curve which is more like a gentle slope and its value is larger than the model (A) and (B).

Upon comparative study of damping constant, natural period of artificial soft upper layer, maximum displacement amplitude ratio and its width, etc., necessary facts were obtained to presume that model supported with piles is most favorable in comparison to the model supported with caisson or settled directly on base stratum which is almost alike.

Detailed examination and consideration of above mentioned experiment, it is quite proper to conclude that as long as pile is not destructed, tall building can be constructed on soft upper layer.

CONCLUSION

In consideration of the relative properties of building and understructure constructed on soft upper layer in the cities of Japan, the artificial soft upper layer utilized in this experiment will be most properly realized to the actual state during the period of 72 hours thru 96 hours after the mixture had been prepared.

Experiment performed under such condition as mentioned above and examination of the resonance of the first and second natural period, indicates that the building supported with pile or caisson can be used for constructing tall building on soft upper layer.

It is permissible to assume that building supported with caisson or settled directly on base stratum responds greater than pile supported building. In other words, the large value of damping constant contributes greatly to minimize the response of resonated vibration in the case of pile supported building.

NOMENCLATURE

A, B, C, D, : Type of foundation considered.

G : Shear rigidity of the model for soil or upper structure.

K_{10} : Coefficient of soil reaction.

T_1 : First natural period of model or artificial soft upper layer.

a : Amplitude of soil surface or top floor vibration, relative to ground floor or shaking table.

a_0 : Amplitude of shaking table.

h : Damping constant.

1, 2, 3, 4, : Measuring point.

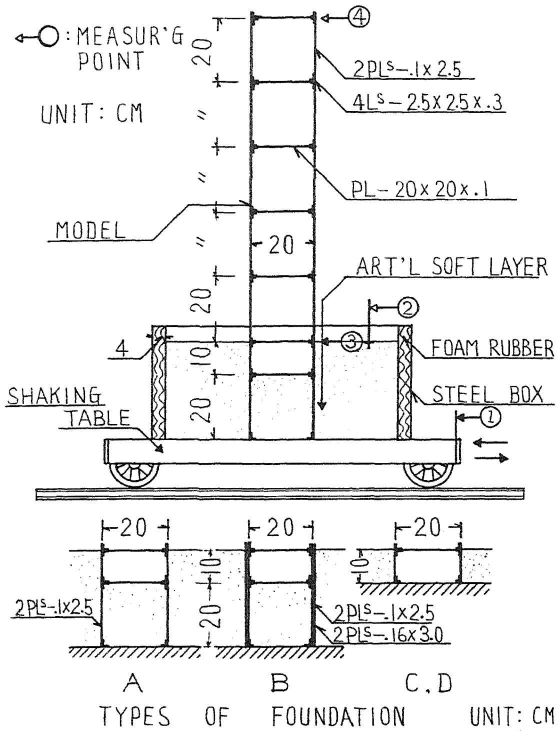

FIG. 1 MODEL, SHAKING TABLE AND TYPES OF FOUNDATION

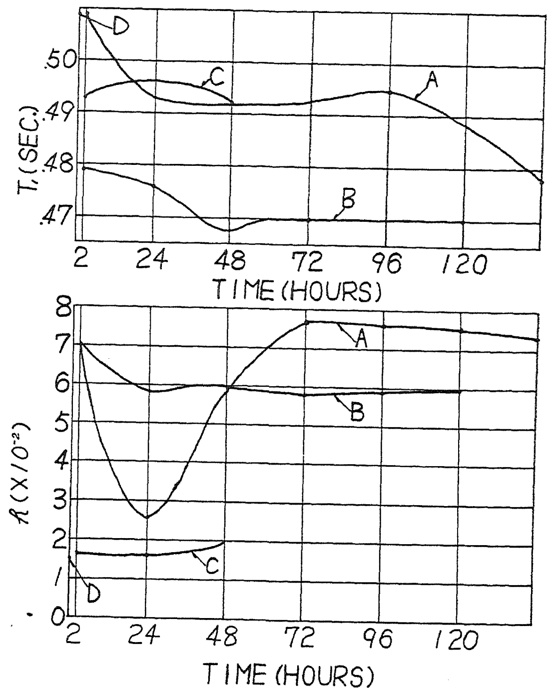

FIG. 2 NATURAL PERIOD AND DAMPING PROPERTIES OF MODEL

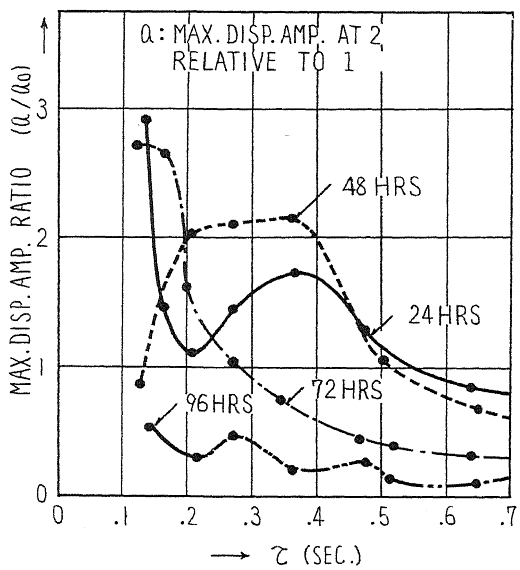

FIG. 3
MAXIMUM DISPLACEMENT AMPLITUDE RELATING TO ELAPSE TIME FROM THE PREPARATION OF ARTIFICIAL SOFT UPPER LAYER

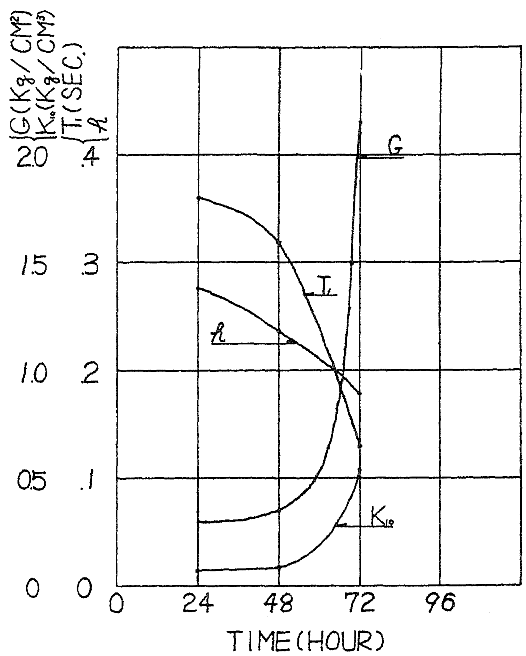

FIG. 4 VIBRATIONAL PROPERTIES OF SOIL RELATED TO TIME LAPSE

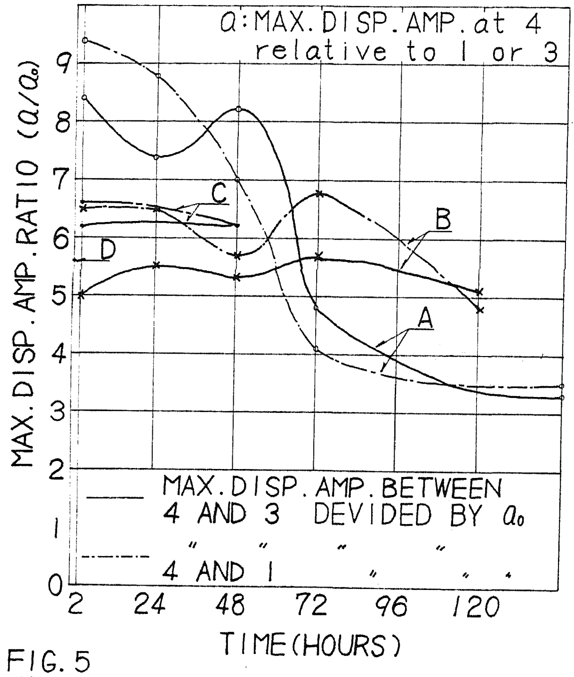

FIG. 5
MAXIMUM DISPLACEMENT AMPLITUDE RELATING TO ELAPSE TIME AND TYPE OF FOUNDATION

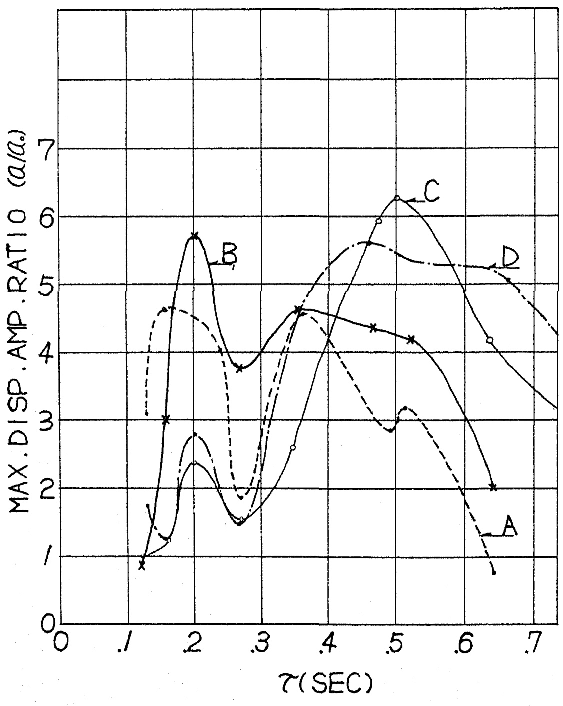

FIG. 6 MAXIMUM DISPLACEMENT AMPLITUDE RELATING TO TYPE OF FOUNDATION

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BY T. TAJIME, S. TERADA, T. MOCHIZUKI

QUESTION BY: A. TORK - NEW ZEALAND

1. Refer to Fig. 5 : How did Building Type C behave after 48 hours? Was Type C tested to 120 hours?
2. Refer to Fig. 6 : Is this graph presented for Time = 72 hours, or for some other time?

AUTHORS' REPLY:

1. Type C was tested to 96 hours, but because the response record of this type was almost alike, observation was omitted.
2. Yes. Graphs of type A and B are for time = 72 hours. Type C which does not change with time elapse is for 48 hours. Type D without surface layer has no relation with time.

QUESTION BY: R.W. CLOUGH - U.S.A.

The conclusion that the building supported on a caisson or directly on a base stratum responds more, is quite misleading. In general, the earthquake excitations applied through the base stratum causes less response in tall buildings. This is because the period of vibration of the building is quite different from the substratum period, but may be quite similar to the surface layer period.

AUTHORS' REPLY:

The natural periods of building and surface layer we consider differ considerably and are each about 3 and 0.8 second. So the earthquake response of a building supported on piles does not enlarge greatly, and large damping of this type decreases the response of this type.

When both natural periods are much closer as in time 2, 24, 48 hours on figure 5, this pile-supported building responds more than other types.