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Multi-columns Foundation for the Tower Piers of a Suspension Bridge

La fondation en colonnes multiples pour les pylônes d'un pont suspendu

Gründung der Pylonen einer Hängebrücke mittels einer Vielzahl von Stützen

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1. Introduction

Japan is an island country composed of four major islands and a few thousand of small islands. Bridges linking the islands have already been constructed over some straits. In area of the straits where the water is deep and the tidal current is fast, it is difficult to construct conventional solid foundations for the longer span bridges. Thus multi-columns foundation systems have recently been applied in these areas for the bridge foundations. A multi-columns foundation is a type of piled foundation, wherein columns are extended above water level and connected to a slab. Table 1 shows some examples of bridge constructed of the multi-columns foundation type.

The survey and research for the bridges linking two of the major islands (Honshu and Shikoku) was initiated almost 20 years ago and as a results of being near its conclusion, the construction of one of these bridges has recently been undertaken. The Honshu-Shikoku Bridge system over the straits of Seto Inland Sea will contain about 20 long span bridges, including suspension, truss, and arch bridges.

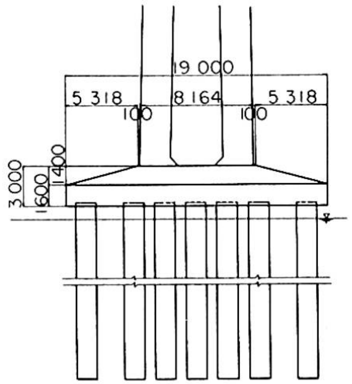
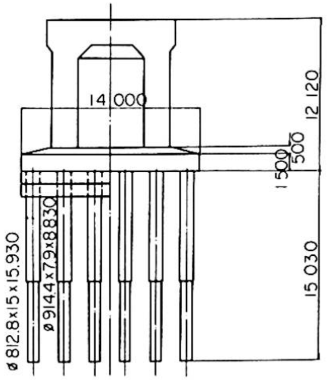
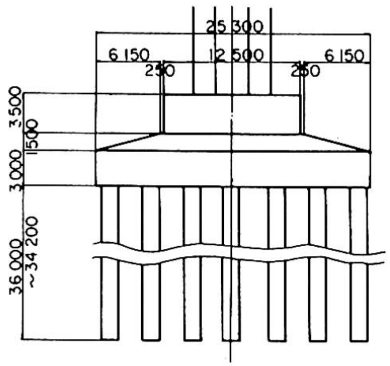
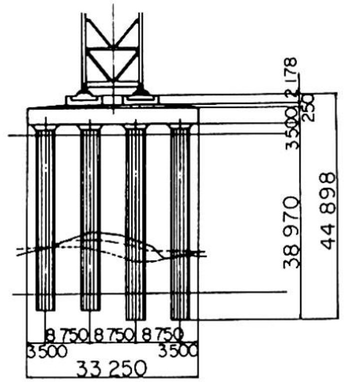
According to the plan, a multi-columns foundation will be used for one of the suspension bridges (Ohnaruto Bridge). The construction site of the Ohnaruto Bridge foundation is to be located in a fast current. In the planning and preliminary designing stages, research was conducted to check the applicability of multi-columns foundations for the suspension bridge towers, including investigation of the static and dynamic behavior of the foundation.(1,2) In addition to our research, some applied experience was obtained by the construction of the multi-columns foundation for the longer span bridge, Ohshima Bridge, which is a 3 span (100-200-100 m) continuous truss bridge constructed by the Japan Highway Public Corporation.(7)

2. Outline of Ohnaruto Bridge

Ohnaruto Bridge is a combined road and railroad bridge as shown in Fig.1. Fig. 2 shows the general view of the multi-columns foundation for Ohnaruto Bridge.

The main characteristics of the design condition at this construction site are as follows:

Table 1 Bridges Constructed on the Multi-Columns Foundation

Name of Bridge	Biwako Bridge	Aoyagi Bridge	Katakami Bridge	Ohshima Bridge
Owner	Siga Prefecture	Gifu Prefecture	Okayama Prefecture	Japan Highway Public Corporation
Year of Completion	1964	1971	1974	1976(Expected)
Total Length of Bridge (m)	1350.0	185.75	520.0	725.0
Span Length of Bridge (m)	95-140-95, Others	20.6, 54.5-54.5-54.5	94-160-120-100	200-325-200
Type of Bridge	Continuous Steel Girder	Composite Girder, 3 Cont. Steel Girder	4 Continuous Steel Box Girder	3 Continuous Truss Girder
General View of Foundation (Ground Condition)	 (Sandy Silt)	 (Sandy Mudstone)	 (Weathered Rhyolite)	 (Granite)
Natural Period of A Foundation (sec)	1.0	0.42	0.83	0.68

* All these details are taken from the plans of each bridge.

(a) Depth of water: 3 m
(b) Speed of tidal current: 5 m/s
(c) Wind speed: 72 m/s
(d) Ground condition: Sandstone

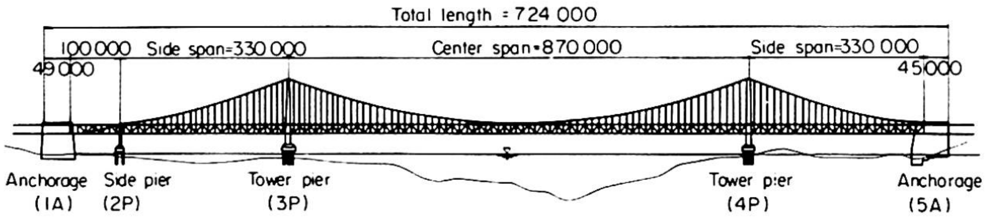


Fig. 1 General view of Ohnaruto Bridge Unit mm

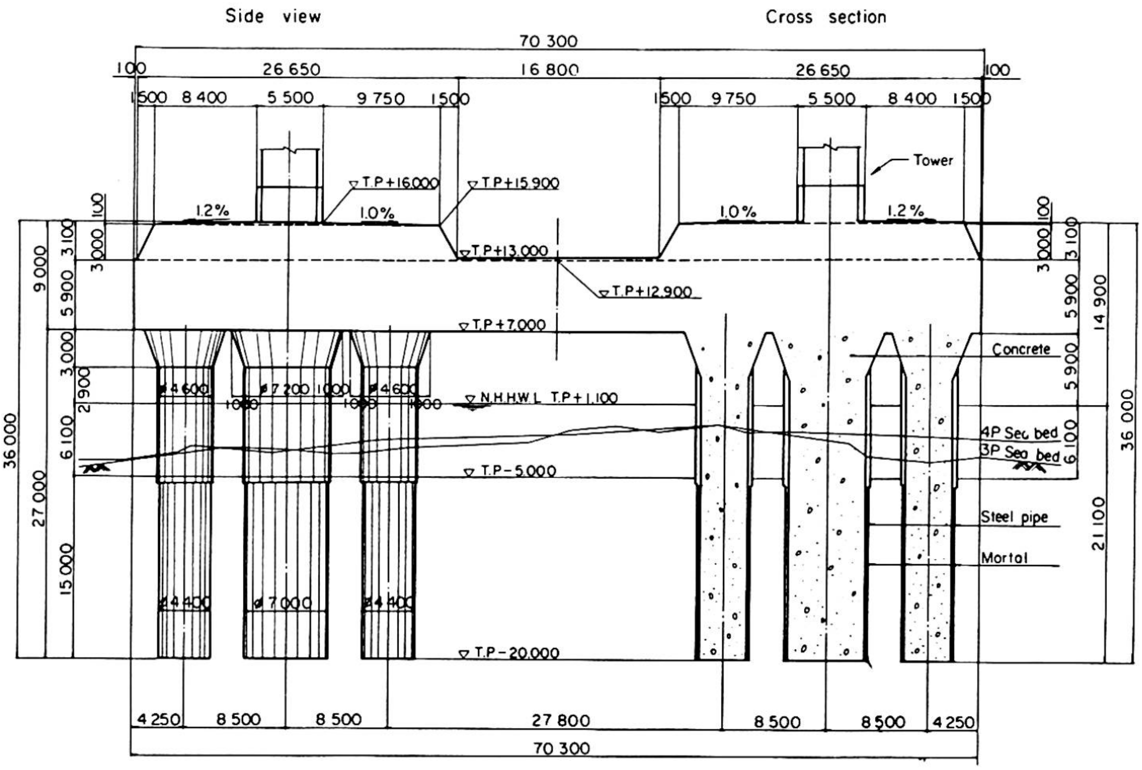


Fig. 2 General view of multi-columns foundation

3. Structural character of multi-columns foundation

A multi-columns foundation has more complicated interaction with the ground, as compared to a conventional solid foundation. It is quite complex to estimate the spring constant and bearing capacity of each column, and then combine the data to determine their interaction as a unitary group of columns. It is also difficult to consider the deep slab effect in the structural analysis and to specify the mass effect of the ground and dumping constant in the calculation of stability during an earthquake. Taking into account all these factors, it seems that a multi-columns foundation can best be analyzed by conceptualizing it as a space frame, as shown in Fig. 3. When a multi-columns foundation is conceptualized and analyzed as a space frame, it is very important to properly define the effective width of the beam and the rigidity of the connection between the beams and columns and to consider the shear deformation of the individual members.

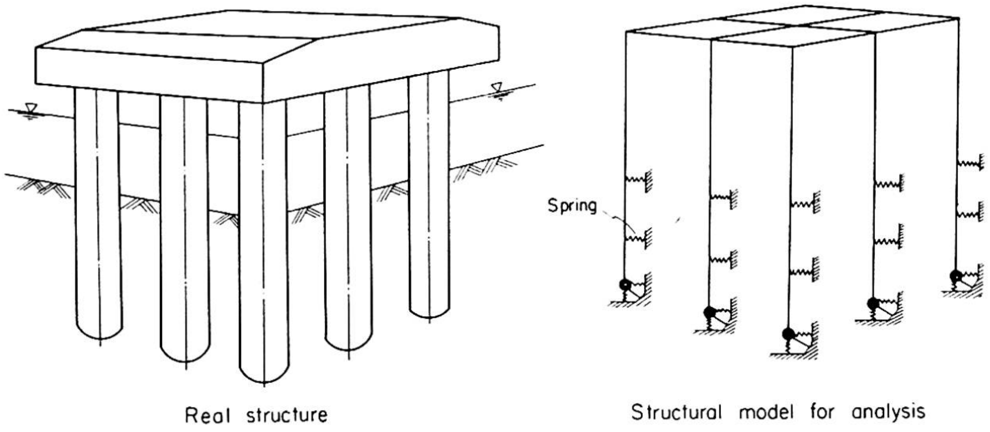
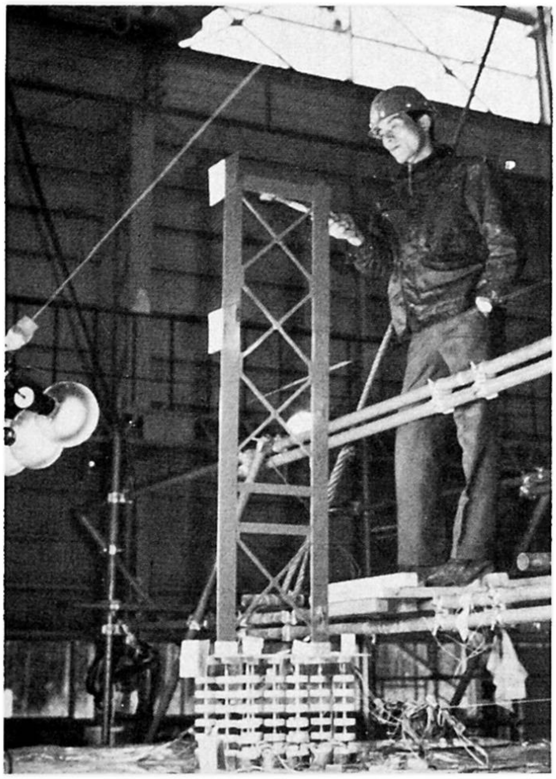


Fig. 3 Simplification of multi-columns foundation for analysis

In order to check the above mentioned method of analysis, some experimental models were built and tests were carried out upon them. Fig. 4 shows the large scale dynamic test model wherein a multi-columns foundation was set on the acrylic amide grouting gel connected to the shaking table.(1,2) In this test, the behavior of multi-columns foundation model was compared with that of a solid foundation model, by measuring the effect of ground deformation and coupled vibration of the tower and foundation. Additionally, dynamic tests of small scale models on sand and large scale models on the real ground were performed.(1, 2,4)

Statical tests of models constructed wholly of reinforced concrete were also performed to determine the load distribution on each column (see Fig. 5).(2)



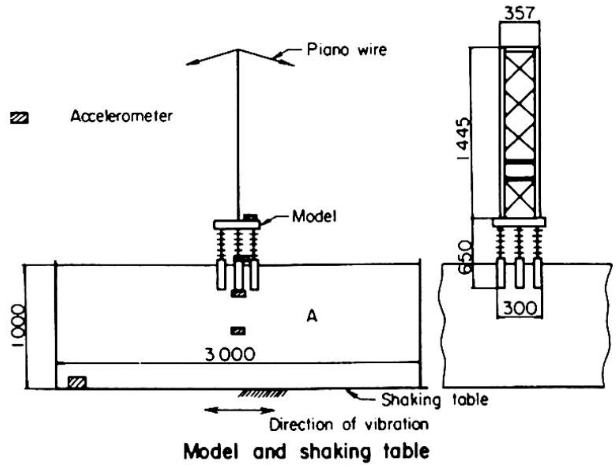


Fig. 4 Dynamic loading test for the tower pier model

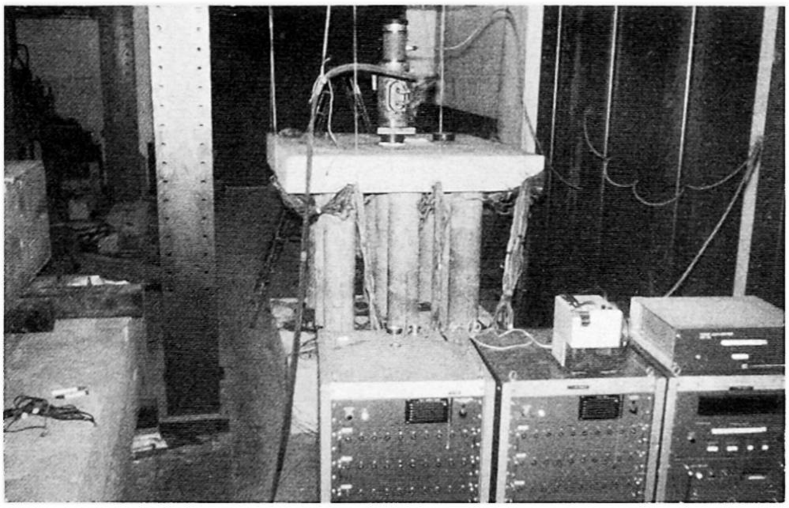


Fig. 5 Static loading test for the multi-columns foundation model

The followings were derived from the experiments:

(a) Although the deformation of the multi-columns foundation is larger than that of the conventional solid foundation, that effect at the tower top is negligible as shown in Fig. 6.

(b) The natural frequency of a multi-columns foundation is higher than that of a solid foundation which is designed to meet the same design conditions, because the weight of the multi-columns foundation is lighter than that of the solid foundation.

(c) Dynamic analysis of tower and multi-columns foundation can be done individually because of the large difference in their natural frequencies.

(d) The first mode of vibration occurs far more often than the others, because the top slab of the foundation is heavy.

(e) A multi-columns foundation can be analyzed as a space frame by the top slab to be a grid beam.

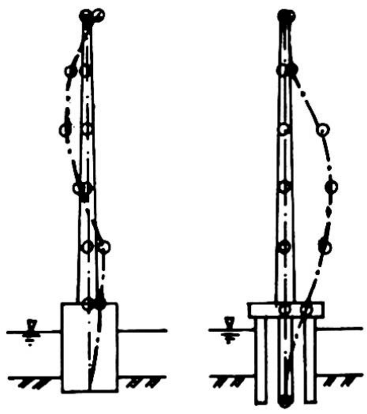


Fig. 6 Typical deformation of tower pier foundations

(f) It is assumed that the horizontal spring constant of the ground to the multi-columns foundation is equal to that of one column multiplied by the number of columns.

Therefore the design of the multi-columns foundation is considered to be reasonable as determined by these various experiments. The vibration tests on the foundations of the Katakami Bridge and Ohshima Bridge showed that it is a practical and feasible structure. (3, 8)

4. Conclusion

It is practical and feasible to use the multi-columns foundation for the suspension bridge tower. The design procedure has been determined by both theoretical and experimental study and expanded upon by actual and increasing construction experience with that gained by various other construction entities.

5. Acknowledgements

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6. References

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SUMMARY

The multi-columns foundation has been recently developed as a foundation to be utilized in construction across deep and fast straits. Applicability of such a foundation to the suspension bridge tower pier has been studied by theoretical analysis and model tests. It is concluded that the multi-columns foundation system for the suspension bridge tower pier is practical and feasible to use.

RESUME

La fondation de pylônes avec colonnes multiples a été dévéloppée récemment comme fondation de ponts de ponts à travers des détroits profonds et à courants rapides. Une analyse théorique et expérimentale avec modèles devait étudier son utilisation possible comme fondation des piles principales de ponts suspendus. Les conclusions montrent que la fondation en colonnes multiques est une solution pratique et réalisable dans ce cas.

ZUSAMMENFASSUNG

Die Gründung mittels einer Vielzahl von Stützen wurde in letzter Zeit für tiefe Meerengen mit erheblicher Strömung entwickelt. Die Anwendbarkeit einer solchen Gründung wurde durch Theorie und Modellversuche überprüft. Es zeigte sich, dass eine Gründung von Pylonen von Hängebrücken mittels einer Vielzahl von Stützen ausführbar ist und Vorteile bietet.