Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 10 (1976)

Artikel: The Tokyo Port tunnel

Autor: Kimura, Yasuhiro

DOI: https://doi.org/10.5169/seals-10485

The Tokyo Port Tunnel

Le tunnel du port de Tokyo

Der Tunnel unter dem Hafen von Tokio

YASUHIRO KIMURA
Head, Bay Shore Route Construction Bureau
Metropolitan Expressway Public Corporation
Tokyo, Japan

1. Introduction

The Tokyo Port Tunnel, a submerged tunnel to which dynamic response analysis and other new technical devices were applied, is located at the First channel of the Port of Tokyo. The tunnel is 1,035m long and the ventilation buildings with cast-in-place tunnels together is 290m. The total length of the cross-tunnel is thus 1,325m. The undersea tunnel consists of 9 prefablicated reinforced concrete elements, each 115m long, 37.5m wide, 8.8m high, as shown in Fig. 1. The ventilation tower measures 48m in height above the ground and 25m in depth underground. The horizontal section is a square shape of about 40m. The soil condition at the construction site is shown in Fig. 2. The surface layer is 43m deep at the west land part, 28m at the sea-bottom and 49m at the east land part.

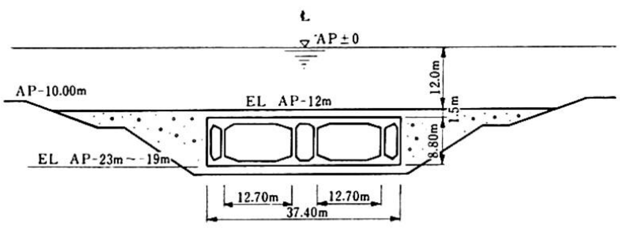

Fig-1 Standard cross section of Tokyo Port Tunnel

2. Earthquake response analysis and earthquake resistant design.

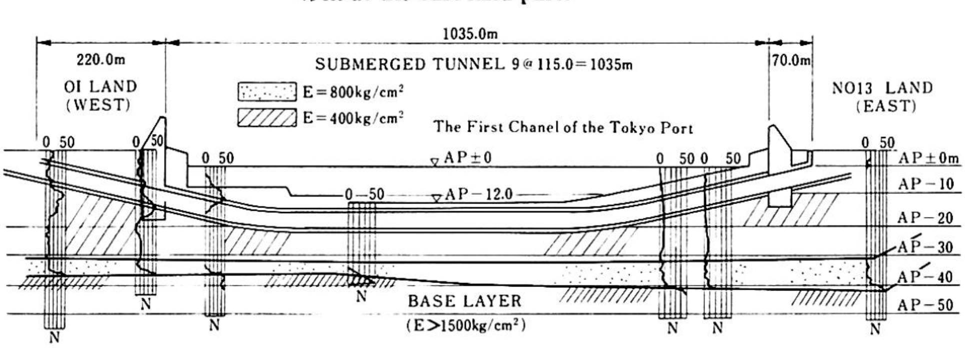

Fig-2 Geologcal map of the site of the Tokyo Port Tunnel

The predominant period of the ground inferred from the results of micro-tremor observation and empirical prospecting is 1.6 sec at the west side, 1.0 sec at the sea-bottom part and 1.8 sec at the east land part, as for the surface layer above Tokyo Gravel layer (base layer, GL-40m ~ -50m). The major part of the surface layer is composed of a very soft clayey soil having an N-value of 0 to 5.

2-1 Earthquake response analysis

Earthquake response analysis on this tunnel was carried out by using the mathematical model which was jointly developed by Dr. OKAMOTO, Dr. TAMURA and HAMADA. And the following calculation and analysis were made by them and the Metropolitan Expressway Public Corp.

Horizontal vibrations are analytically divided into two directions along the tunnel axis and prependicular to it as shown in Fig. 3.

The ground from the west side to the east side, 1,325m long in total, was divided into 46 slices of 30m in thickness, and the distance between adjacent masses was taken as 30m.

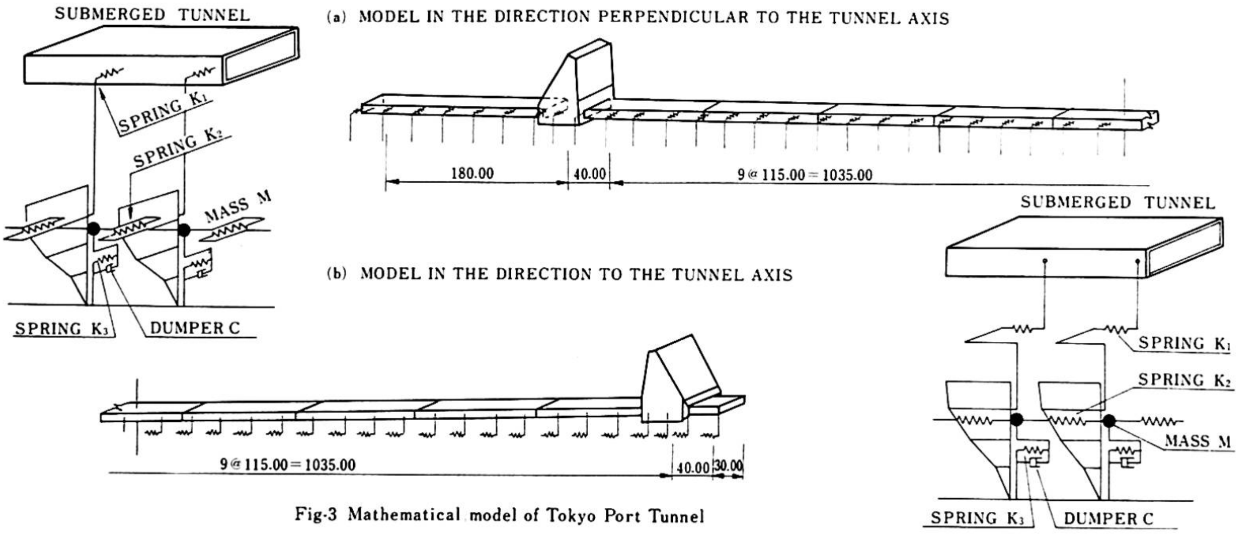

Fig-3 Mathematical model of Tokyo Port Tunnel

Responses in two directions were calculated mainly by using EL Centro NS 1940 and Aomori NS 1968 (Off-Tokachi Earthquake) records as in-put seismic waves, the latter having comparably longer period when compared with the former. As a result of calculations, the followings were learned:

1) The distribution shapes of maximum values of bending moment, shearing force, axial force and displacement of the tunnel are all very similar each other, but the magnitudes of stress and displacement differ considerably depending on the input seismic waves.
2) Changes in dynamic characteristics of the ground along the tunnel axis, such as at the slope of the ground, give great influence on the stress in the tunnel during earthquake.
3) Relative displacement between the tunnel and the ground is smaller for vibration in the lateral direction than in the axial direction.

In the mathematical model, dynamic characteristics of the ground was represented by the one mass-one spring system equivalent to the fundamental shear vibration of the ground. To clarify the influence of the higher order mode of the ground motion, response displacement analysis were performed with Aomori NS and EL Centro NS, taking natural modes up to the third order of the ground into account. The result showed only several percent difference at most, so it was made clear that the displacement of the ground at the site could surely be represented by that of the mathematical model.

2-2 Effects of joints between Tunnel Elements

From the fact that stress distributions along the tunnel axis were very similar regardless of different type of input seismic waves, it became possible to develop an earthquake resistant design method for the submerged tunnel. For this purpose trial calculations were made for several cases.

In Fig. 4, case 1 shows a case that neither hinged joints nor spring joints are constructed, in case 2 hinged joints are constructed at points 5 and 32, and in case 3 at points 5 and 28. In case 4, spring joints are inserted for all the joints between tunnel elements.

For input seismic waves, Aomori, NS, 1968, maximum acceleration being modified to 100 gals, was adopted in analysis. From a result of the calculations, the following were made clear:

1) The hinged joint is effective to make bending moment and shearing force diminish, but its range of effectiveness is limited within about 100m from the joint for this tunnel.
2) Hinged joints make the tunnel flexible more, however restriction against deformation diminishes, and a small increase of stress is caused, as a result, at a portion fairly apart from the hinged point.
3) When spring joints are constructed between all elements, bending moment, shearing force and axial force decrease by nearly 50%.
4) Only a small increase is observed for the displacement of the tunnel by the insertion of hinged or spring joints. When hinged joints or spring joints are to be constructed, much care should be exercised in determining their positions.

2-3 Effects of Joints between Tunnel and Ventilation Tower

In the case of this Tunnel, the site of ventilation towers were so planned as to locate at the both ends of the tunnel on its axis. Since the ventilation tower shows different behavior during earthquakes, it was expected that large stress may be generated in the tunnel around the terminal joints. In this connection, three cases were considered. In case 1, the tower and the tunnel are made movable independently each other, in case 2 are connected by means of hinges (only for the lateral vibration), and in case 3 are rigidly connected.

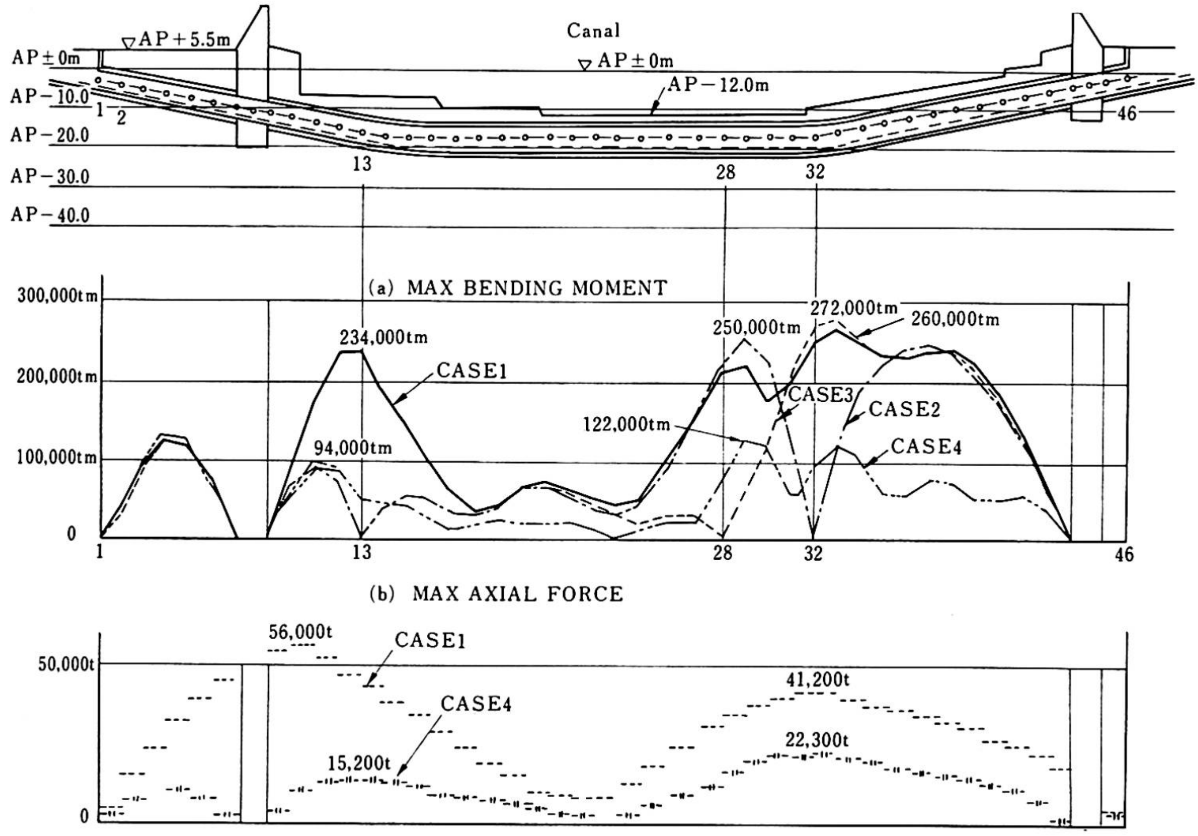

Fig-4 Influence of hinged joints and free joints on stresses of the tunnel

As easely understood from Fig. 5, considerably large bending moments are generated near the ventilation tower, and steeply decrease with the distance from the ventilation tower and same tendency goes for axial force too. The maximum bending moments caused at points more than 150m apart from the ventilation tower are almost same for all cases.

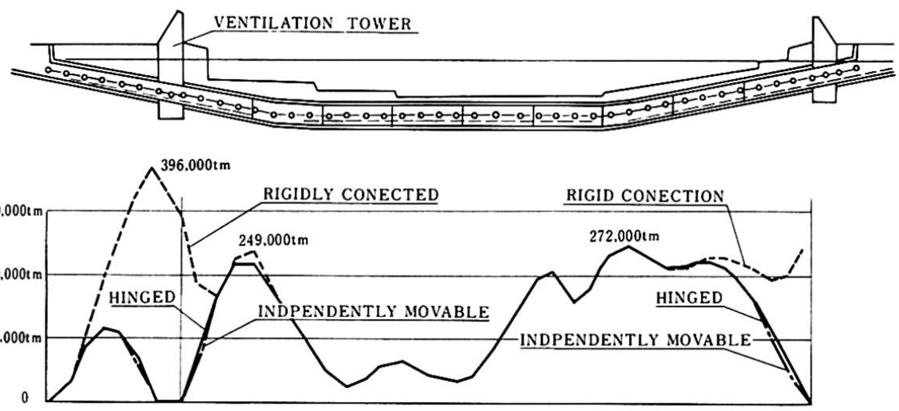

Fig-5 Influence of joints between the tunned and the ventilation tower on berding moment of the tunnel

Similarly, Fig. 5 indicates that extent of about 250m from the tower is under influence regarding axial force.

In both cases of the hinged and free joints, the values of the maximum bending moment are equal, and considerably small when compared with the values in the case of rigid connection. From the above-mentioned results, it is recommended that terminal joint between the tunnel and the ventilation tower should be made as flexible laterally and movable axially as possible in order to reduce stress concentration near the tower to the minimum.

2-4 Joint Structure actually applied

Fig. 6 shows the joint details actually applied at the first joint and the joint is able to move ± 4 cm horizontally and + 4 cm axially toward the approach tunnels, but the movement toward the sea bottom side is restrained under 10 cm by the function of SEEE Cables specially installed between the ventilation building and adjoining element.

Fig. 7 shows ordinary joint details. Utilizing the joint space, both horizontal and vertical shearing key, and the second water proofing, etc. are installed, and the upper side of the joint space is covered with specially devised Ω type steel plate against bending moment, axial force and shearing power which is generated at the primary stage of earthquake motion.

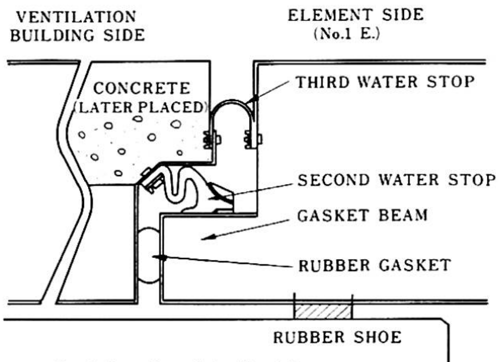

Fig-6 Detailes of the firt joint

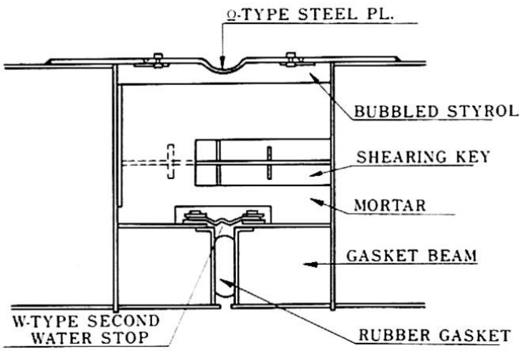

Fig-7 Detailes of the Flexible joint

3. Motar Grouting

Up to this time, what is called "Sand Jetting Method" has been used in the treatment of foundation of ordinary submerged tunnel with big cross section. However in this tunnel, mortar grouting method was newly developed. This method has such a great merit that the process of filling up the space between undersurface of a element and sea bottom is not disturbed by weather or sea condition, and also grout mortar itself has wide variety in choice.

3-1 Bentonite Mortar

The strength of grout mortar for the foundation of element is good enough with low strength. So much importance was rather attached to how to fill up the space as completely as possible. Several kinds of grout mortar were studied, for example, bentonite mortar, air bubble mortar and silt mortar. The bentonite mortar was adopted in a result.

The strength comes down by using bentonite as admixture, however it became possible to raise the filling up ratio with effect of the improvement of workability in lean mix mortar, prevention of material segrigation and continuity of fluidity for long hours. The following experiments were carried out prior to execution, and data for actual execution were obtained.

(A) Bentonite mortar proportion test
(B) Small sized grouting test
(C) Large sized (same as actual size) grouting-test

As a result of experiments, it was confirmed that more than 80% at minimum can surely be filled up.

Following is a standard proportion of bentonite mortar.

Cement	Bentonite	Water	Sand	Rital	per $1m^3$ Flow Value
150kg	37.5kg	647kg	750kg	1.5kg	14 – 18 sec

In the actual execution, the strength of bentonite mortar were fairly scattered, however, its strength was $\sigma 7=1.46$, $\sigma 14=2.49$ and $\sigma 28=3.42kg/cm^2$ on the average.

3-2 Mortar Grouting

Prior to grouting, the clearance between under-surface of a element and sea bottom was measured just under all grouting holes by using mortar level meter (super sonic wave detector). Approximate volume of mortar to be grouted was calculated by data obtained.

The order of grouting was principally carried out in accordance with the chart shown in Fig. 8. According to the mortar flow test, the mortar does not flow uniformly in all directions, but in some direction, showing something like belt with 2 – 3 m width, and the mortar flows in other directions similarly, when the initial flow stops. Referring to this mortar flow behaviour, the mortar level meters were arranged at the suitable holes.

In order to prevent grout mortar to leak outside the projected plane of a element, mortar stoppers were applied, namely long mortar bag in the direction perpendicular to the tunnel axis, and crushed sand stone buried at the both sides of a element in axial direction.

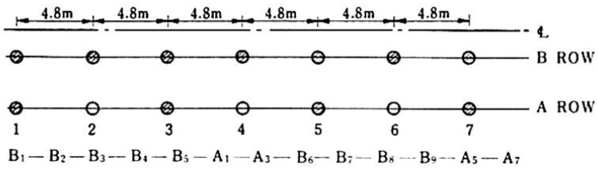

Fig-8 Order of mortal grauting

Effectiveness of grouted mortar was confirmed by comparing a theoretically estimated value of settlement of a element with actual settlement generated when the vertical jacks which were provided at the both sides of the top end of a element were released.

4. Countermeasure for Consolidation Settlement

In a result of the past several years' survey, settlement of alluvial layer supporting the tunnel, was thought to arise in future, being caused by silt layer's consolidation itself and the drop of underground water level in the diluvial gravel layer, mainly around eastern half of the tunnel. This drop of water level was caused by over pumping up for industrial use, but this underground water level is maintained at -7 m for these years by the severe government regulation.

In a result of comprehensive study, the settlement of the ground was estimated -10 cm at the center, -30 to 40 cm at the eastern end and negligible at the western half of the tunnel respectively. In this circumstances, the followings were considered for countermeasures.

1) replacing silt layer with sand
2) driving sand piles
3) to promote consolidation by preloading
4) rising up the underground water level
5) application of pile foundation

These methods were studied from such points of views as cost, construction period, construction process and effects of application. However the point of application was how to secure a continuity of the supporting condition to the elements.

For this purpose, a pile system which can follow the ground settlement to some extent and finally get settled on a ideal vertical line was studied. In ordinary piles, such as friction piles and semi-supporting piles which are both able to give a certain degree settlement, it is very difficult to secure prearranged settlement calculated from the settlement line.

In this circumstance, a pile, which functions as supporting pile ultimately by the operation of some divice put on the top of a pile, when the element reaches prearranged settlement, was developed.

This special device is shown in Fig. 9.

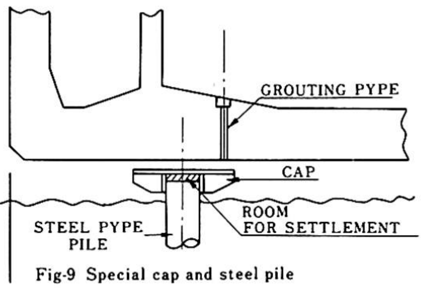

Fig-9 Special cap and steel pile

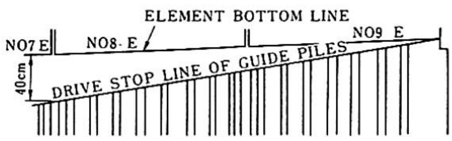

Fig-10 Pile arrangement in the axial direction

This cap, made from steel plate, is placed on the pile top, when steel pipe pile is driven. It is not necessary for a pile to be driven to accurate level position, as far as the cap with proper settlement allowance is placed on regular position because the space between the undersurface of element and sea bottom is filled by grout mortar.

Piles were cross sectionally so positioned just under grouting holes that grout mortar can surely fill up the space.

Piles were set from the end element (the 9th element) up to the quarter point of the 7th element, in such a manner that the settlement allowance changes in a straight line along the axis with 40 cm just under the joint between 7th and 8th element and no margine under the terminal joint, taking such all feasible conditions into consideration as allowable deformation of element, flexibility of joint and the development process of ground settlement, etc.

5. Bibliography

1) Earthquake Observation on Trench Type Subaqueous Tunnel.
Report of The Institute of Industrial Science, The University of Tokyo. By Chosiro TAMURA, Shunzo OKAMOTO, Katsuyuki KATO, Yoshitaka NAKAGAWA.
2) Dynamic Behavior of Submerged Tunnel during Earthquake.
Report of the same Establishment. By Chosiro TAMURA, Shunzo OKAMOTO, Masanori HAMADA.

6. Summary

The anti-earthquake design and construction of the submerged tunnel on the soft ground are presented. The analytical technique conducted herein is widely applicable to the earthquake resistant design of submerged tunnel. The seismometer observation now being carried out will provide the data to improve the method of analysis.

New technique of grouting into the bottom of the tunnel operated inside of the elements seems to be used widely in off-shore structures.

Newly developed capped piles foundation is also a good countermeasure against ground settlement.

SUMMARY

The anti-earthquake design and construction of the submerged tunnel on the soft ground are presented. The analytical technique conducted herein is widely applicable to the earthquake resistant design of submerged tunnel. A seismometer observation now being carried out will provide the data to improve the method of analysis. New technique of grouting into the bottom of the tunnel operated inside of the elements seems to be used widely in off-shore structures. Newly developed capped piles foundation is also a good countermeasure against ground settlement.

RESUME

L'étude anti-sismique et la construction d'un tunnel immergé sur des fondations compressibles sont présentées. La méthode analytique employée s'applique facilement à l'étude de la résistance aux tremblements de terre. Les observations actuellement réalisées par sismographe donneront des informations permettant d'améliorer cette méthode analytique. Il semble possible d'utiliser pour des ouvrages d'art martimes, la nouvelle technique d'injection de coulis de mortier sous tunnel à partir de l'intérieur des éléments. La nouvelle technique de fondation par pieux avec têtes élargies semble aussi une bonne solution contre les tassements importants.

ZUSAMMENFASSUNG

Ueber die Untersuchung des Verhaltens gegenüber Erdbeben von abgesenkten Tunnels auf nachgiebigem Baugrund wird berichtet. Die verwendete Berechnungsmethode eignet sich gut für die Ermittlung des Tragwerkwiderstandes gegenüber Erdbeben. Im Gang befindliche Messungen mit Seismografen werden Ergebnisse liefern, die eine Verbesserung der Berechnung gestatten. Die neu entwickelte Methode, vom Innern der Tunnel-Elemente aus den Zwischenraum zwischen Bauwerk und Baugrund zu injizieren, eignet sich ganz allgemein für überflutete Bauwerke. Ebenso erscheint die Verwendung von Pfahlfundationen mit vergrösserten Pfahlköpfen als gutes Mittel gegen Baugrundsetzungen.