Chapter 15

Tunnel Excavation

15.1 General

(1) The seismic design of tunnel excavation, is located in this chapter.

(2) In the seismic design of tunnel excavation, to the design ground motion and load based on "Chapter 3 Design ground motion and load", by considering the influence of ground displacement during an earthquake, carried out a verification that the structure satisfies the seismic performance required.

(Commentary)

Verification of seismic performance of tunnel excavation, in order to the structure satisfies the seismic performance specified, carried out a verification about damage level of the element and stability of tunnel excavation. The tunnel excavation is unlike a upper structure. Effect of the inertial force is small, and because the deformation of the surrounding ground, the behavior is dominated. In seismic design, we shall consider the effect of ground displacement during an earthquake.

15.2 Load

Design load to be used in the seismic design of tunnel excavation, combination of design load, and load factor, in addition by the "3.7 Load", shall take into account the load affecting the tunnels excavation.

(Commentary)

Design loads to be used in the seismic design of tunnel excavation and combinations thereof, in general, in addition by the "3.7 Load", it is necessary to take into account properly the ground during an earthquake and interaction of the structure. In addition, in liquefied ground, based on the "6.8. 5. Tunnels Excavation", we must also consider the effects of liquefaction of the ground. An example of the combination of design loads and load factors are shown in table 15. 2.1.

Table 15. 2.1

An example of the combination of design loads and load factors

Type of Load	L1 Ground Motion	L2 Ground Motion
Fixed dead load	1.0	1.0
Additional dead load	1.0	1.0
Earth pressure as a permanent load	1.0	1.0
Earth pressure as a variable load	1.0	1.0
Water pressure, buoyancy (flat water)	1.0	1.0
Effect of lateral movement of the ground*1	-	-
Impact of the earthquake	1.0	1.0

Note) Load of *1 will consider if necessary.

15.3 Calculation of the response value

15.3.1 General

Structural analysis of tunnel excavation, in consideration of ground conditions, structural conditions, etc., in addition by the "6.7 Calculation of the response value of tunnel excavation", will doing by one of the following methods.

◎ (1) Seismic deformation method; responded displacement method

(2) Simple responded displacement method

(3) Dynamic response analysis

(Commentary)

Calculation of the response value of tunnel excavation, in consideration of ground conditions, structure conditions, for L1 ground motion and L2 ground motion specified in "3.3 Configuration of design ground motions", will be made by suitable technique to obtain a response value required for verification of seismic performance.

1) Structural analysis method

In a similar manner to the "6.7.2 Calculation of the response value", select the appropriate method.

For the general tunnel excavation, it is good to use "15.3.2 Responded displacement method". In addition, in general scale of tunnel excavation, if considered ground side is uniform, it is preferable by the "15.3.3 Simple responded displacement method". When performing detailed studies, and if the structure conditions and ground conditions are complex, dynamic nonlinear analysis of the time history can take into account the non-linear behavior of the structure and ground, and interaction of the structure and ground (See the "15.3.4 Dynamic response analysis ").

2) Calculation of the response value

Verification for element damage levels according to "15.3.2 Responded displacement method" and "15.3.3 Simple responded displacement method" is verification against damage state of the element is in a state of the assumed load is all loaded. It is desirable if while the assumed load is loading step by step, seeking a horizontal displacement relationship between layer shear force and interlayer in each load step, to understand the damage situation of the element.

In addition, fracture morphology of the element shown in "7.3.1 Element property" is the whole system of the structure by nonlinear static analysis that takes into account the material correction factor, in principle be found by loading a load up to the ultimate state. However, if the shear span of the ultimate state can be assumed by a single element and the maximum shear force V_{mu} from the response value that does not take into account the material correction factor can be estimated, it is not limited thereto.

In consideration for the L1 ground motion, because it is a principle to the yield strength within the element, it can be analyzed as a linear element. In this case, by confirming that occurrence bending moment is surrender bending moment, it can be determined that the damage is on level 1.

In consideration for the L2 ground motion, even by using whichever of the analysis method, study of damage level of element, in principle be in accordance with non-linear analysis. However, if it is predicted that the amount of deformation response is small (the deformation angle of the whole structure is about 1/100), it is also good to be investigate the seismic performance in a simple manner, regardless of the nonlinear analysis. In other words, by the method of "simple response displacement method", etc., if the amount of deformation response of the structure could be predicted, about the center pillar, etc., deformation performance is calculated from element as both ends fixed beam. It is preferable as the examination of damage level if confirming the response interlayer deformation amount or more, etc. of the entire structure type. However, for the top deck and side walls, impact of the permanent load is large. It is necessary to examine properly in a way that takes into account that impact.

Study of L1 earthquake is using the L1 ground motion specified in "3.3.2 Setting of the L1 ground motion", in principle to consider by "15.3.2 Responded displacement method", "15.3.3 Simple responded displacement method", and "15.3.4 Dynamic response analysis". However, when performing the examination in a simple manner, by the "6.4.2 Calculation of ground displacement" to the L1 ground motion, calculates the amount of the relative deformation of the ground at the position of the structure top and bottom deck. It is assumed that the amount of deformation is the amount of deformation response of the structure of the L1 during earthquakes. It is good to be carried out the verification of damage level of the element by using a damaged condition in load step to be the amount of deformation of the L1 during earthquakes of the study results for the L2 ground motion.

15.3.2 Seismic deformation method; responded displacement method

◎ **Typical method in Japan**

15.3.2.1 General

In the structure analysis by responded displacement method, performed modeling of structure and ground by "15.3.2.2 Model of structure" and the "15.3.2.3 Model of ground". By the "15.3.2.4 Calculation of response value", calculate the response values required for verification of seismic performance.

(Commentary)

Underground structure is unlike the upper structure which have a large impact of the inertial force. Because it is behaves following the behavior of the surrounding ground, we can predict well the accuracy and the dynamic behavior of the surrounding ground. Also by static analysis such as responded displacement method, etc., it is possible to calculate well, a relatively accurate response value. Therefore, for the non-complex general underground structures, it is preferable by static analysis method such as the responded displacement method, etc.

The concept of the responded displacement method is shown in figure 15.3.1. In general, tunnel excavation can be analyzed by modeling the framework structure which is supported by the ground spring. In addition, the ground spring, responded displacement method was represented by finite element also been developed. Over the appropriate consideration, it is also possible to use.

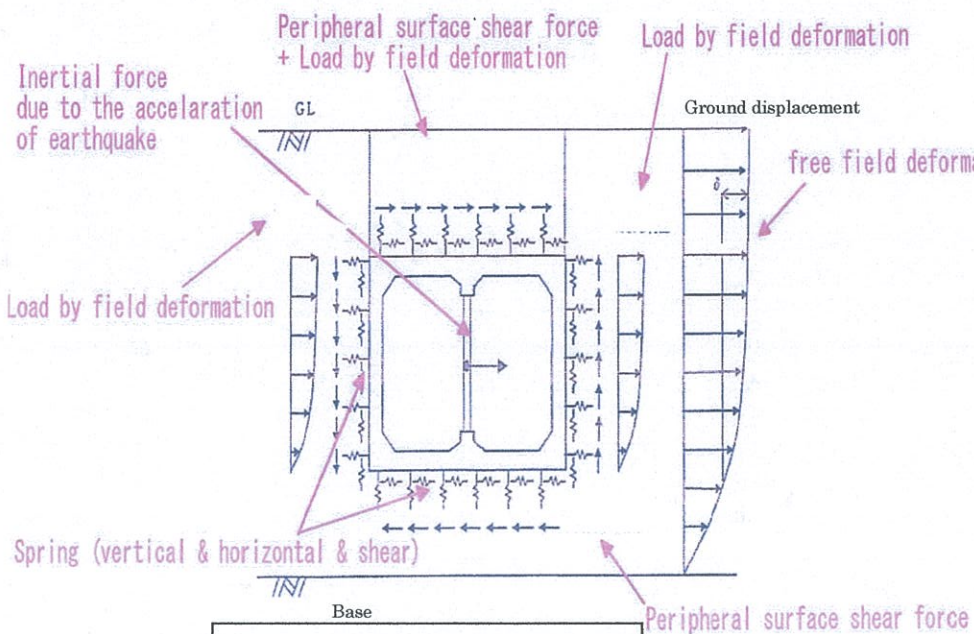

Figure 15.3.1

The concept of responded displacement method

15.3.2.2 Model of the structure

The structure apply the responded displacement method, the modeled as a wire generally, and take into account the non-linearity.

(Commentary)

About (1)

The structural analysis model, in principle be modeled in the same manner as "Chapter 10 Rahmen structure."

In consideration of the line perpendicular direction, the structure will be modeled as a rahmen structure. It is composed of deck, side wall, and center pillar (wall). Each element is modeled as a wire, axis position is good as the centroid position of the respective element.

In general, for the center pillar structure, it is good to be considered as a two-dimensional model that takes into account the column spacing. If the shape is complex, or if the structure is considered to be inappropriate to carry out an analysis on two-dimensional, it is preferable to carry out the three-dimensional analysis.

In addition, if the shear wall is present in the line perpendicular direction, based with the "Chapter 8 Bridge pier", in consideration of the appropriate dynamic properties, it is preferable to be modeled.

Non-linearity of the elements, in principle be due to "7.3 Reinforced concrete element" - "7.6 Steel element".

15.3.2.3 Modeling of the ground

Ground of the structure surrounding in responded displacement method, be modeled as a spring ground to support the structure. The non-linearity will be considered by the stiffness degradation in response to the strain level of the ground during an earthquake.

(Commentary)

In responded displacement method, evaluating properly the ground spring is important. On the ground spring, ground conditions such as the thickness of the overburden, distance to the foundation and structure, etc., shape and dimensions such as width, height, etc. of the structure, deformation mode of ground and structure during earthquakes, and the strain level of the ground during an earthquake, etc. will be considered. It is necessary to calculate it properly. In general, it is good as an elastic spring and is calculated by formula (15.3.1) - (15.3.4) [1)]. However, if the calculation accuracy of the response value is bad such as particularly the width of the structure is larger than the height or the height of the structure is larger than the width[1)], it is desirable to be corrected properly the value of the ground spring. If the layer structure of the ground in the structure side is changing, please calculate the ground spring for each layer.

It is desirable to consider about peeling between the ground and structure, and the effect of slip. In the general scale of structure and the ground, the effect is small, can be ignored[2)]. However, in wide or tall structure, etc., if it is considered that the effects of the peeling-slip is large, it is preferable to consider that effects.

Here, on the modulus of transverse elasticity of the ground for determining the deformation modulus of the ground, if the impact of the earthquake have calculated by dynamic analysis of the ground 1) as shown in "15.3.2.4 Calculation of response value" (Commentary), it can be calculated as the value of shear modulus obtained by dividing the shear strain and shear force at the time of occurrence maximum shear strain, etc. In addition, 2) if you want to calculate easily the impact of the earthquake, it can be calculated from design shear elastic wave wave velocity.

1) Vertical subgrade reaction coefficient of top and bottom deck

$$k_v = 1.7\ E_o B_v^{-3/4} \qquad (15.3.1)$$

Herein,

k_v : Vertical ground reaction force coefficient of top and bottom deck (kN/ m^3)

E_o : Deformation coefficient of ground (kN/ m^2)

B_v : Width of the top and bottom deck (m)

2) Shear subgrade reaction coefficient of top and bottom deck

$$k_{sv} = k_v / 3 \qquad (15.3.2)$$

Herein,

k_{sv} : Shear ground reaction force coefficient of top and bottom deck (kN/ m^3)

k_v : Vertical ground reaction force coefficient of top and bottom deck (kN/ m^3)

3) Horizontal subgrade reaction coefficient of side

$$k_h = 1.7\ E_o B_h^{-3/4} \qquad (15.3.3)$$

Herein,

k_h : Horizontal subgrade reaction coefficient of side (kN/ m^3)

E_o : Deformation coefficient of ground (kN/ m^2)

B_h : Side wall height (m)

4) Shear subgrade reaction coefficient of side

$$k_{sh} = k_h / 3 \qquad (15.3.4)$$

Herein,

k_{sh} : Shear subgrade reaction coefficient of side (kN/ m^3)

k_h : Horizontal subgrade reaction coefficient of side (kN/ m^3)

5) Deformation coefficient of ground

$$E_o = 2G_d\ (1 + v) \qquad (15.3.5)$$

Herein,

E_o : Deformation coefficient of ground (kN/ m^2)

G_d : Design shear elastic coefficient (kN/ m^2)

v : Dynamic poisson's ratio

(Preferably,

the depth of the groundwater level in the alluvial and diluvial ground : 0.50,

the shallow of the groundwater level in the alluvial and diluvial ground: 0.45,

soft rock: 0.40, and hard rock: 0.30)

In addition, design shear elastic coefficient can calculated by formula (15.3.6-1) and (15.3.6-2). However, out of necessity, when calculating V_{sOd} from the N-value, the value obtained by dividing the f_g^2 with G_d which shown in formula (15.3.6-1) and (15.3.6-2), shall be treated as G_d. The reason is due to the following. In other words, the ground survey factor fg which introduced when calculating the V_{sOd} from N value without implementing PS logging, taking into account the accuracy of the estimation formula of shear wave velocity and N values, was considered to be calculated the small shear elastic wave velocity. In general, shear elastic wave velocity is small. In other words, when estimated that ground stiffness is small, the large amount of ground deformation has been evaluated, and design of the safety side is possible. However, in design of tunnel excavation, generally, the stiffness of the ground is less than the structure is often. In that case, when evaluated that ground stiffness in other words ground spring is small, ground deformation is absorbed into the ground spring, and hard to be transmitted to the structure. Therefore, though acceleration and ground displacement is large evaluated, but the ground spring is small, the ground displacement is not transmitted to the structure and can not be designed for the safe side. Therein, if V_{sOd} was calculated from the N-value, only the inertial force and ground displacement is large evaluated. If the ground spring considered reasonable to use a value f_g = 1.0, in consideration of f_g, it is corrected by dividing f_g^2 and G_d which was calculated.

a) If determine the impact of earthquake by dynamic response analysis of the ground

$$G_d = \tau_d / \gamma_d \qquad (15.3.6\text{-}1)$$

Herein,

G_d : Design shear elastic coefficient (kN/ m²)

τ_d : Design shear stress in ground response analysis (kN/ m²)

γ_d : Design shear strain in ground response analysis

b) If calculate easily the impact of earthquake

$$G_d = \gamma_t (\alpha_d V_{sOd})^2 / g \qquad (15.3.6\text{-}2)$$

Herein,

γ_t : Weight of unit volume (kN/ m³)

V_{sOd} : Design initial shear elastic wave velocity (m/ s)

α_g : Stiffness reduction coefficient of the ground by strain level during earthquakes, in accordance with table 5.7.2.

g : Acceleration of gravity (9.8 m/ s²)

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1) Kosuke Murotani - Seiya Nishiyama - Akihiko Nishimura : Study on the applicability of the responded displacement method and study of ground spring in seismic design of multi-layer tunnel excavation, 9th tunnel engineering research presentation association, 1999.11 (submitted).

2) Seiya Nishiyama - Kosuke Murotani - Akihiko Nishimura : Structure - peeling

between the ground - effect of slip on the behavior during an earthquake of tunnel excavation, 25th earthquake engineering research presentation association, pp. 493 - 496, 1999. 7.

15.3.2.4 Calculation of the response value

Response value by the responded displacement method is calculated in consideration as a static load of the effects of earthquake.

(Commentary)

Calculation of response value in responded displacement method, the principle is take into account by replacing the static load of the following earthquake impact, to obtain an index for verification the damage level of the elements. In other words, performs a static nonlinear frame analysis considering the effects of earthquakes, to get response curvature, rotation angle, occurrence section force, etc. of the element.

Impact of the earthquake in responded displacement method is consider A) inertial force, b) ground displacement, and c) a peripheral surface shear force as the principle.

These impact of the earthquake, in principle is calculated by dynamic analysis of the natural ground. However, other than the ground that require detailed consideration if amplification characteristics of the ground is complex because the geological structure is complex, characteristics of the ground is greatly changed during an earthquake, etc., it is also good to calculate the impact of the earthquake at each depth of the structure from the maximum displacement and maximum acceleration amount of the land surface of ground classification G1-G7 (if determine the effects of the earthquake conveniently).

1) Calculate an impact of earthquake by dynamic analysis of ground

Calculation of earthquake impact by dynamic analysis of ground is calculated based on appropriate analysis method by the "5.7.3 Dynamic analysis of ground".

Impact of the earthquake is momentarily changing. But, in general, focuses on vertical distribution of the amount of ground displacement. The relative displacement between the top and bottom deck structures using the response value of time to become the largest.

However, in the case of multi-layer structure, because geological structure is complex, if the strata of different impedance extremely exists on the side of the structure, etc., if the relative displacement of the ground between the top and bottom deck layers is maximum, necessarily, the most stringent state on the structure is not exist. In this case, it is preferable to calculate the impact of the earthquake by focusing also at the time become maximum the ground displacement on each layer of structure.

a) Inertial force

Inertial force used in the responded displacement method is calculated by multiplying the structure and the design seismic intensity. Design horizontal seismic coefficient is good to be calculated by dividing the acceleration of gravity and the absolute acceleration on the structure gravity position at the target time.

The effect of inertial force in the vertical direction is generally small, not important to be considered. However, if it is determined that the impact of vertical motion is large according to structure format and load conditions, in a similar manner to

"3.3.1 General" (commentary), it is preferable to consider the 0.5 multiple of the horizontal ground motion of the base surface.

b) Ground displacement

The relative displacement between the top and bottom deck structures is using the response value at the time to become maximum. The amount of displacement is enter as forced displacement through the ground spring end. If the end of the ground spring it is an elastic spring which is fixed, a load obtained by multiplying the displacement with the value of ground spring is equivalent to loading.

c) Peripheral surface shear force

A peripheral surface in contact to the ground and structure is considered to circumferential shear forces. It is calculated from the results of the response analysis of ground at the target time. Top deck and bottom deck is loading a shear force of the ground, on position of the upper surface of top deck and the lower surface of bottom deck. In addition, for the side walls, the shear force of the ground on the center position of the side wall to the total height of the sidewall is allowed to act. However, if the layer structure of the ground is changed in the side wall position, please calculate the shear force in each layer, and act in the interval.

2) Calculate easily the effects of earthquake

If you want to easily calculate the impact of the earthquake, select the classification that applies to the target ground from the ground classification of G1-G7 which described in "5.7.2.2 Ground classification", and calculate the value corresponding to the ground classification.

a) Inertial force

By using the maximum acceleration, in base and maximum acceleration of the ground surface of the corresponding ground that shown in "5.7.2.3 ground surface design ground motion," and "Appendix 5-5", on the assumption that it is varies linearly in the surface layers, it is good to seeking acceleration at the position of the center of gravity of the structure. In this case, 1) Calculate the impact of the earthquake by dynamic analysis, a) Calculate the inertial force with similarly inertial force.

b) Ground displacement

"6.4.2 Calculation of the ground displacement" (Commentary) 2) to calculate easily the vertical distribution of ground displacement.

c) Peripheral surface shear force

"6.4.2 Calculation of the ground displacement " (Commentary) 2) to calculate easily the vertical distribution of ground displacement, calculate the shear strain by differentiating the each depth of the ground displacement which was calculated, calculated by multiplying the shear elastic coefficient G of the ground determined from design shear elastic wave velocity. Loading method of the peripheral surface shear force to the side wall is in a similar manner 1) if you want to calculate the impact of earthquake by dynamic analysis of the ground.

In addition, the peripheral surface shear force does not exceed the shear strength of the ground in natural ground.

15.3.3 Simple responded displacement method

On tunnel excavation with general scale, if the ground conditions and the structure is simple, it is possible to calculate the response value by simple responded displacement method.

(Commentary) Applicable condition → C & C: 1 layer 2 span, uniform ground

Extent between the two diameters of one layer of tunnel excavation on a general scale, if ground conditions on the structure side regarded uniformly and relatively simple, it is good to verify the seismic performance by simple responded displacement method.

Simple responded displacement method of tunnel excavation, is a method to predict amount of deformation response of the structure, by multiplying coefficients in the amount deformation of the natural ground. This coefficients is called the response coefficients (α_r).

The study flow of simple responded displacement method is shown in figure 15.3.2, and the concept of response coefficient is shown in figure 15.3.3.

1) Calculation of the response coefficient

Response coefficient can be calculated by using the formula (15.3.7). This calculation formula is using stiffness ratio of the ground and structure (Gg / Gs), shape ratio (b / h), depth ratio (H2/ H1), etc. as a parameter, and conduct the two-dimensional finite element analysis. The relationship between amount of displacement of the natural ground and amount of displacement of the structure which obtained by that results is a coefficient that is set on the safe side[1].

We think difficult to apply simple responded displacement method. And can not convince the Engineer.

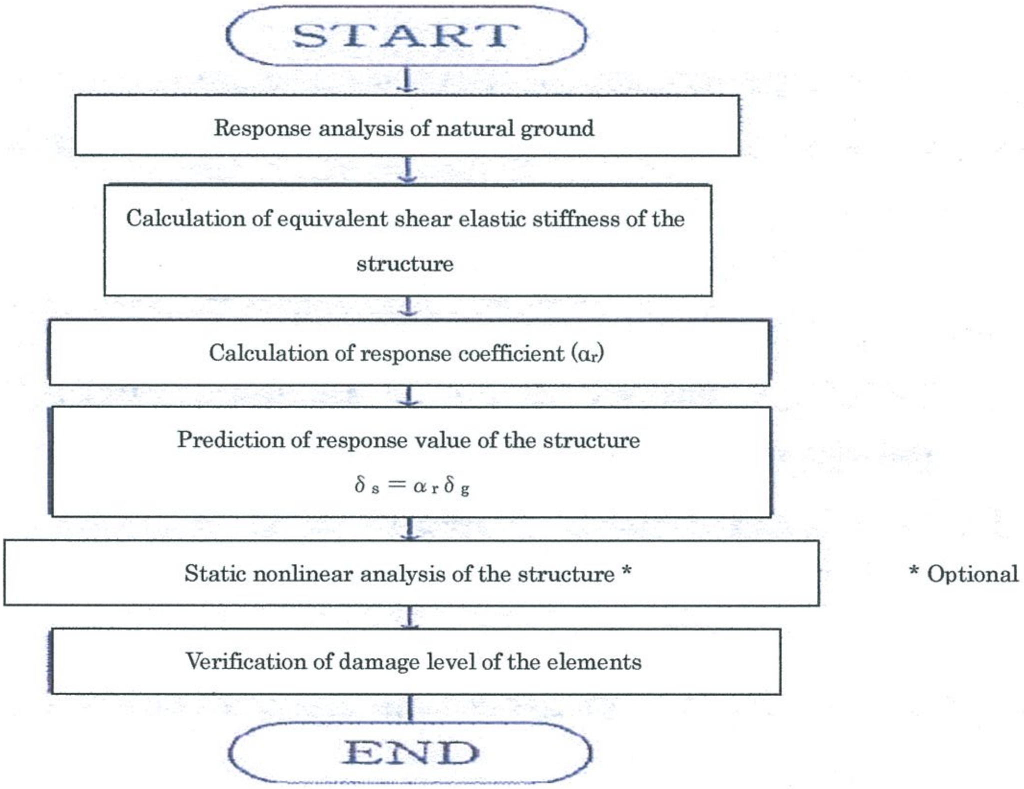

Figure 15.3.2 Study flow by simple responded displacement method

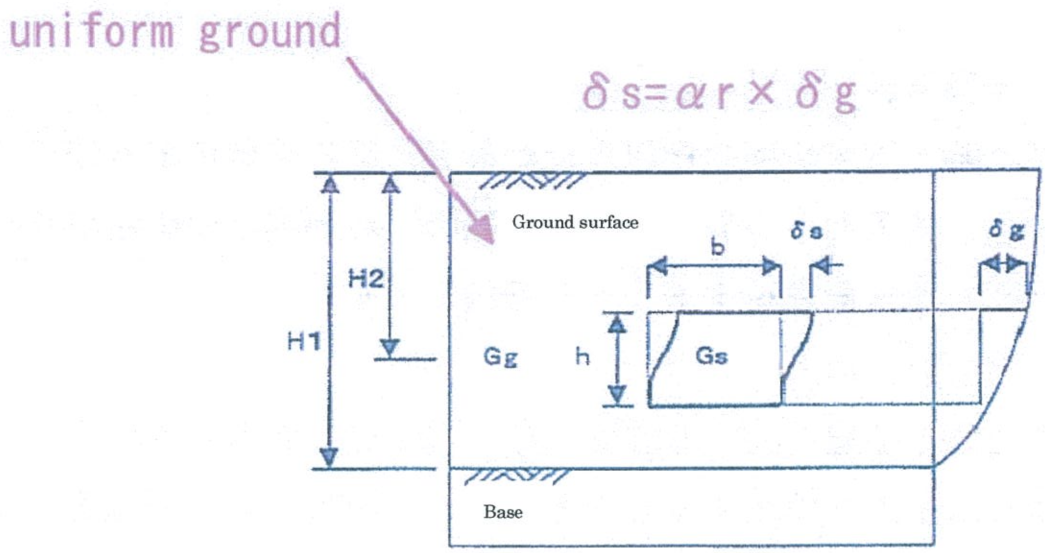

Figure 15.3.3 Figure of the concept of response coefficients

$$\delta_s = \alpha_r \delta_g$$

δ_s : Response interlaminar deformation amount of structure

δ_g : Response interlaminar deformation amount of natural ground

(Corresponding to the depth of each layer of the structure)

α_r : Response coefficients between the most top and bottom of deck

$$\alpha_r = f\{G_g/ G_s, b/ h, H_1/ H_2, \text{etc.}\}$$

G_g : Shear elastic coefficient of ground

G_s : Equivalent shear elastic coefficient of structure

H_1 : Distance from ground surface until base

H_2 : Distance from ground surface until structure center position

$$\alpha_r = 1.1 \times (a \cdot 1n (G_g/ G_s) + b) \qquad (15.3.7)$$

$$a = 0.091 (b/ h) + 0.053 (H1/ H2) - 0.07$$

$$b = -0.036 (b/ h) + 0.40 (H1/ H2) + 0.92$$

2) Equivalent shear elastic coefficient of structure

Equivalent shear elastic coefficient of the structure which required to calculate the response coefficients as shown in figure 15.3.4, can be calculated by assuming simple support of structures.

Non-linearity of the structure, in general, in the study of L1 ground motion, is 0.5 EI_0, in the study of L2 ground motion, deformation angle of the structure up to 1/ 150 is 0.2 EI_0, up to 1/ 100 is 0.15 EI_0. Over the entire structure, the entire cross-section effective stiffness can be estimated by an equivalent stiffness which was reduced by rigidity uniformly. The relative deformation angle of the structure, if more than 1/ 100, although it is good to make the settings in detail, in general, as 0.1 EI_0 is good. In addition, in the setting of equivalent stiffness, the amount deformation of the structure is good to assumed same with a amount deformation of natural ground. This is, based on the relationship between deformation angle of the structure and stiffness degradation rate which was investigated for general tunnel excavation (ratio of initial stiffness EI_o and equivalent stiffness EI_{eq}), the lower equivalent stiffness is a value which was set in consideration to be calculated on the safe side of the amount of deformation.

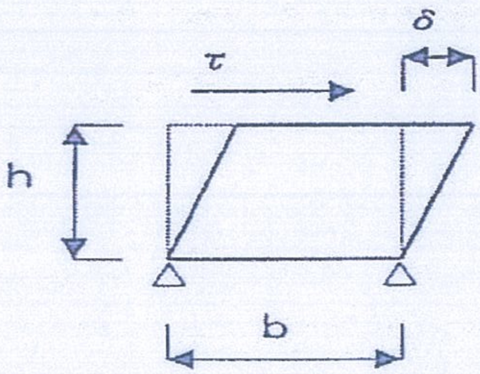

Figure 15.3.4 Calculation of the equivalent shear elastic coefficient

Equivalent shear elastic coefficient of structure

$$G_s = \tau / \gamma$$

$$= \tau / (\delta / h)$$

G_s : Equivalent shear elastic stiffness of structure (kN/m^2)

τ: Shear stress (kN/m^2)

δ: Interlaminar deformation amount of structure (m)

h : Height of a structure (m)

γ: Strain of a structure (deformation angle)

3) Calculation of response value

If you want to verify the damage level of the elements, the principle is conduct a static non-linear analysis by non-linear frame analysis model, in a same manner as

"15.3.2.4 Calculation of response value". But, if the amount of deformation of the structure is small, may be carried out the verification of damage level of the elements with a simple technique.

If by static nonlinear analysis, impact of the earthquake is calculated by using a frame analysis model as shown in figure 15.3.5. The load applied to the structure, as a result of the interaction of structure and ground, in order to load onto the structural model directly, no need to consider a ground spring.

Horizontal load to the loading, the principle is think about the appropriate load form, depending on the ground conditions and structure. In general, on both sides of the side wall, the bottom deck is 0, it is good as a distribution load of triangle to enlarge the top deck surface. However, a wide of structure compared to a height of a structure (the wide is 2 times higher or more), etc. is the interaction forces in the normal direction of the side wall and the shear force of the peripheral surface of the upper surface of the top deck. Size and ratio of that load is vary depending on the ground and structure conditions. However, in consideration of the ease of design, depending on the structural form, may be simplified.

By using these loads, loading the loads until δ_s which was determined by a response coefficient of deformation amount between the structure layer, and perform a study of damage level of the elements in a state that wasδ_s.

In addition, in this case, non-linear characteristics is calculated by using the axial force of the permanent load condition. Also, axial force which used for strength verification, etc. is used the axial force of the permanent load condition. By aggregate thing of load condition which idealized the effects of earthquakes, the representation of the axial force distribution is become difficult.

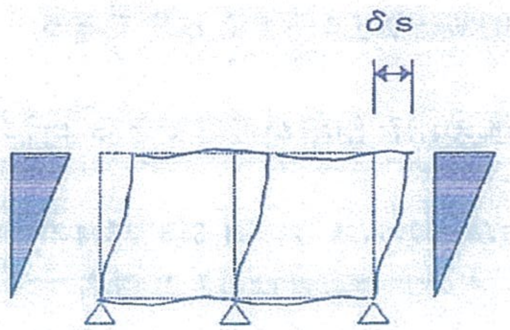

Figure 15.3.5 Analysis model if by the static nonlinear analysis

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15.3.4 Dynamic analysis method

Response value by dynamic analysis method is consider the nonlinearity of structure and ground, and calculate the structure and the ground by analytical model which was integrated.

(Commentary)

If an underground structure is support a building or pier, or even alone is wide extremely, if the structure is complicated such as the multilayer structure is high, if the ground configuration is complex, etc., it is desirable to examine by dynamic analysis method.

In the dynamic analysis, roughly, there is a technique based on sequential

integration method and method based on equivalent linearization method. Because behavior of underground structures is greatly affected by the surrounding ground, analysis accuracy of the ground is important. Characteristic of these analysis methods is shown in "5.7.3 Dynamic analysis method of the ground." related to one-dimensional analysis of ground. These terms, in reference, select the appropriate analysis method.
Structure and modeling of the ground, in order to effect mutual between the two can be considered, the structure and ground be modeled as a unit, and considering the appropriate nonlinearity.

The structure, to be able to express properly the behavior of the earthquake, the principle is be modeled in accordance with "6.3.3 Modeling of the elements" and "Chapter 10 Rahmen structure", the non-linearity is according to "7.3 Reinforced concrete elements", etc.

Setting of the base surface is conform to "3.4 Configuring the base surface of the seismic design". The nonlinearity and the ground surface layer, in principle be accordance with "5.7.3 Dynamic analysis method of the ground". The ground is modeled in order to represent properly the impact on the structure during an earthquake. Also, semi-infinite of the ground is properly consider. It is desirable to consider the structure, peeling between the ground, and effect of the slip.

In addition, in dynamic analysis, if the nonlinearity of the structural element can not be considered directly, it is preferable by the method shown in "Appendix 15-2."
In addition, it is necessary to be careful about the handling of the permanent load. If you do own weight analysis without considering the construction process generally, it will become a stress state different from the actual. In general, it is good to do initial

stress in dynamic analysis initial stress which was calculated in design for permanent load.

15.4 Verification of seismic performance

Verification of seismic performance of tunnel excavation, in addition by "7.10 Tunnels excavation ", is doing by the following.

(1) Damage level of the elements is verified by "7.3 Reinforced concrete element", "7.4 Steel-reinforced concrete element", "7.5 Concrete-filled steel tubular element", and "7.6 Steel element", depending on the type of elements.

(2) The stable is verified by liquefaction, about subsidence and lifting of the structure.

(Commentary)

Confirm by appropriate indicators, that you meet the seismic performance of structures which was set in the same manner as "2.2.2 Seismic performance of the structure".

About (2)

For tunnel excavation, in the normal ground, a problem with respect to stable is less. If there is a problem with the stable of seismic, in order to be considered only if the ground is liquefied, determined in this way.

If it is determined to liquefaction the surrounding ground of the tunnel excavation by the "5.5 Determination of liquefaction of sandy ground ", it shall be by "6.8.5 Tunnel excavation".

In addition, stable level can be determined by referring to the following.

If the liquefaction does not occur, or for the liquefaction, appropriate countermeasure construction was given, or although the liquefaction occurs, it is determined that lifting does not occur by the formula (6.8.3) it is become a stable level 1.

If it is determined that by liquefaction, subsidence and lifting on the structure is occur but, impact of running of the train after the earthquake is small, it is becomes stable level 2.

If it is determined that subsidence and lifting on the structure is occur, and impact of running of the train after the earthquake is large, but the entire system of the structure does not collapse, it is become stable level 3.

15.5 Earthquake-resistant structure details

Earthquake-resistant structure details of the tunnel excavation is shall be by "10.5 earthquake-resistant structure details".

(Commentary)

Seismic structure details of tunnel excavation, in addition by "10.5 earthquake-resistant structure details", "Design standards of railway structure, etc. - Commentary (Basic structure - Structure of the anti-earth pressure) " of "Chapter 10 Box culvert", to be able to ensure the deformation performance required during an earthquake, defining appropriately of each structural element is the principle. Furthermore, to be able to resist deformation of the line direction, it is necessary to determine the placement of the longitudinal bars of the line direction, and the detail of the joint portion of the structure.

Conventionally, if the seismic design was not performed, establishment of longitudinal bars of the side walls and deck, and installation direction of shear reinforcement, has been defined for stress state when the permanent load. However, because there is a possibility that the alternating stress is affect during an earthquake, in a similar manner to Rahmen Structure, in order to be expected sufficient deformation performance of the elements, it will be made a reinforcement. Especially, it is necessary to pay attention the corner and site to predict the plastic hinge is formed.

In the earthquake of the southern part of Hyogo Prefecture, it have been identified deviation damage on the starting point of the haunch and side walls on strokes joint of the upper and lower portions of the side walls. In order to prevent damage like that, it is preferable to strokes joint of the construction not in the same location with the hinge.

In addition, for the water leakage from the structure joints and the body post-earthquake, it is desirable take adequate measures.

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