「社会基盤学」問題冊子
Question Booklet of "Civil Engineering"

2023 年度　大学院入試
東京大学大学院工学系研究科社会基盤学専攻　修士課程

The 2023 Entrance Examination
Master's program, Department of Civil Engineering,
Graduate School of Engineering, The University of Tokyo

2022 年 8 月 29 日（月）　9:00 – 12:00（日本時間）
August 29th, 2022 (Monday) 9:00 – 12:00 (in JST)

分野 1 (Field 1)	構造・設計	(Structures / Design)
分野 2 (Field 2)	材料・地盤	(Concrete engineering / Geotechnical engineering).
分野 3 (Field 3)	水圏工学	(Hydrospheric engineering)
分野 4 (Field 4)	交通・空間情報	(Transportation / Spatial information engineering)
分野 5 (Field 5)	都市・景観	(Urban / Landscape)
分野 6 (Field 6)	国際プロジェクト・マネジメント	(International project / Management)

注意事項 / Notices

- 日本語もしくは英語で、手書きで解答すること。Answers must be handwritten in Japanese or English.
- 事前に申告した２分野に対して解答すること。申告と異なる分野の回答は採点されません。Answer the questions in the two exam fields which you have selected in advance. If you answer questions in exam fields different from your selection, your answers will not be scored.
- 分野ごとに、指定された解答用紙を使用してください。Please use the designated answer sheets for each exam field.
- すべての解答用紙の受験番号欄に受験番号を記入してください。Please fill your examinee number for all the answer sheets.
- 本試験はオープンブック形式の試験です。インターネットを含め、ノートや参考書を使用しても構いません。Examinees are permitted to refer to any documents including materials on the website to answer the questions (Open book style).
- 試験終了後、分野ごとに解答用紙を指定されたサイトにアップロードしてください。白紙答案の場合も、アップロードは必要です。After the exam, please upload your answer sheets for each exam field to the designated website. You need to upload your answer sheets even if they are blank.
- 試験終了後、解答用紙は速達書留で社会基盤学専攻に郵送してください。Answer sheets should be mailed to the Department of Civil Engineering, University of Tokyo by postal mail using registered express mail.

分野 1 /Field 1 (Structures / Design)

Question 1

Fig. 1.1 shows a cantilever beam subjected to a point load P. The beam is made of a linear elastic material with the Young's modulus E, and has the sectional area $A = 2h \times b$. w is the bending induced downward displacement of the beam. Answer all the following questions assuming that the deformations are infinitesimally small, and the Euler-Bernoulli beam theory (i.e., simple beam theory) is valid for this beam.

(1) Consider the bending induced deformation of the beam segment of infinitesimal length dx shown in Fig. 1.2(b). The radius of curvature of the neutral plane of the deformed beam segment is R. Obtain expressions for the axial strain, ϵ, and stress, σ, of a fiber located y distance from the neutral plane when the ends are subjected to a moment M.

(2) Obtain an expression for the bending induced elastic energy, $H = \frac{1}{2}\int_V \sigma\epsilon \, dV$, of the beam in terms of I, E and R, where V is the volume of the beam, I is the second moment of the area, and $\frac{1}{R} = \frac{d^2w}{dx^2}$.

(3) For the cantilever beam shown in Fig. 1.1, w can be approximated as $w = \alpha x^3 + \beta x^2$, where α and β are constants. Let $\Delta H = H - W$, where H is the elastic energy stored in the system and W is the work done by the force P. $W = Pw(L)$, where $w(L)$ is the displacement at $x = L$. Find α and β by minimizing ΔH with respect to α and β (i.e., by setting $\frac{\partial \Delta H}{\partial \alpha} = 0$ and $\frac{\partial \Delta H}{\partial \beta} = 0$).

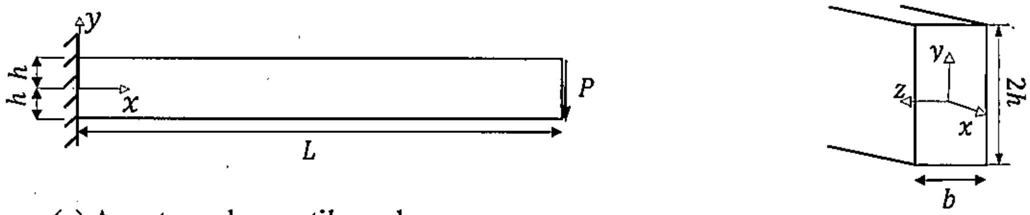
(4) In addition to bending moments, shear forces also contribute to the deformation of beams. The shear induced downward displacement u (see Fig. 1.2(c)) of a beam can be approximately estimated using the differential equation $G\frac{du}{dx} = \frac{P}{A}$, where $G = \frac{E}{2(1+\nu)}$ is the shear modulus and ν is the Poisson's ratio.

a) Find the shear induced deformation, u, of the beam shown in Fig. 1.1 as a function of x.
b) Prove that the shear induced deformation of the cantilever beam shown in Fig. 1.1 is negligibly small compared to bending induced deformation (i.e., $u \ll w$).

(5) Consider that the left end of the beam is connected to a linear rotational spring of stiffness k as shown in Fig. 1.3. The geometric and material properties of the beam are identical to those of the beam shown in Fig. 1.1. Ignore any shear induced deformations.

a) Write an expression for the $\Delta H' = H' - W'$ of the new system, where H' is the elastic energy stored in the new system and W' is the new work done by force P.
b) Propose a suitable polynomial to approximate the new downward deformation, w', of the beam. Briefly explain the reasons for your choice of the approximation.
c) Find the unknown coefficients of the polynomial you proposed.

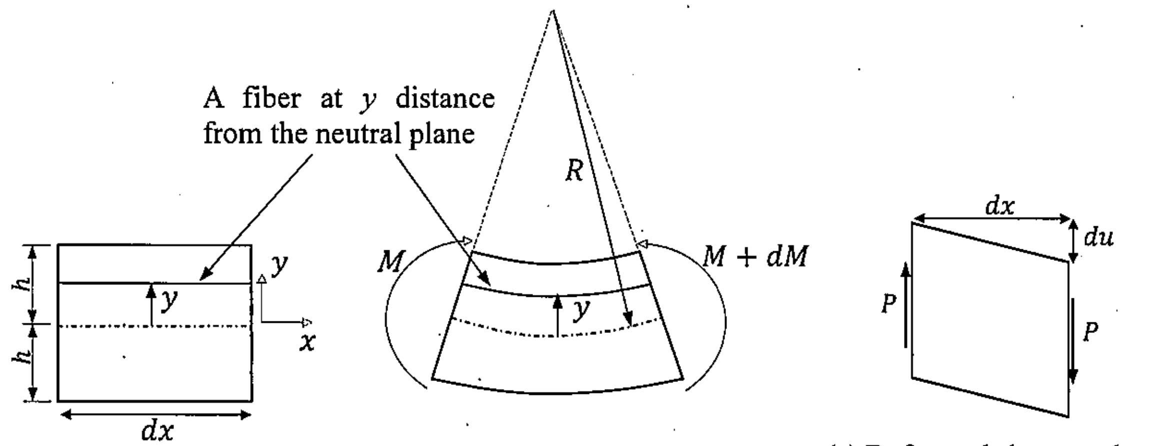
cantilever beam: 片持ち梁, Young's modulus: ヤング率, infinitesimally small: 無限小, Euler-Bernoulli beam theory: ベルヌーイ・オイラー梁理論, radius of curvature: 曲率半径, neutral plane: 中立面, elastic energy: 弾性エネルギー, second moment of area: 断面二次モーメント, downward displacement: 下方変位, rotational spring: 回転バネ, polynomial: 多項式, shear modulus: せん断弾性率



(a) A rectangular cantilever beam

(b) Cross-section

Figure 1.1: A rectangular beam with cross sectional dimensions $2h \times b$, and length L.



(a) Undeformed shape

(b) Deformed shape under a bending moment M

(c) Deformed shape under a shear force P

Figure 1.2: Undeformed and deformed shapes of an infinitesimal beam segment of length dx when subjected to a bending moment M and shear force P.

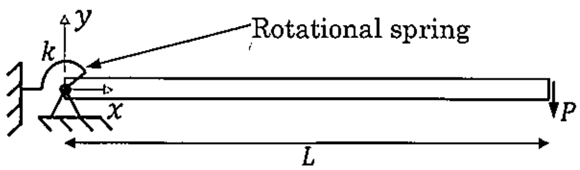


Figure 1.3: A beam connected to a rotational spring.

分野 1 /Field 1: (Structures / Design)

Question 2

Fig. 2.1(a) shows a newly developed hysteretic damper utilized to suppress the vibration of a single-degree-of-freedom system. The system is subjected to a sinusoidal load $P(t)$ that induces the steady-state vibration. The load is defined as Eq. 2.1.

$$P(t) = P_0 \sin(\omega t) \tag{2.1}$$

Here, P_0 is a constant and ω is the angular frequency. k and m are the stiffness and mass of the system in which the damper is installed. Let t denote time. The displacement of the mass is $x(t)$. Fig. 2.1(b) shows the forces acting on the mass including the elastic resistance force F_S, the damping force F_D, and $P(t)$. For this damper, the relationship between the damping force F_D and the displacement x under steady-state conditions is shown in Fig. 2.2. Starting from the origin 0, the cycle continues to point 1, point 2, point 0, point 3, point 4, and finally returns to the origin. This relationship can be mathematically described as Eq. 2.2.

$$F_D = \eta k |x| \operatorname{sgn}(\dot{x}) \tag{2.2}$$

Here, the parameter η is a property of the damper assignable by the designer and $\operatorname{sgn}(\dot{x})$ is defined as Eq. 2.3.

$$\operatorname{sgn}(\dot{x}) = \begin{cases} -1 & \text{for } \dot{x} < 0 \\ 0 & \text{for } \dot{x} = 0 \\ 1 & \text{for } \dot{x} > 0 \end{cases} \tag{2.3}$$

In dynamics, damping is usually represented by viscous damping, which is the simplest form of damping since the governing differential equation of motion is linear. Assuming this hysteretic damper could be approximated by an equivalent viscous damper, answer the following questions.

(1) The damper dissipates the vibration energy E_D, which can be calculated by the work done by the damping force, i.e., $E_D = \int F_D \, dx$. Let x_0 denote the maximum displacement of the mass. Obtain the energy dissipation by the hysteretic damper during one cycle of the motion.

(2) The most common method for defining equivalent viscous damping is to equate the energy dissipated in a vibration cycle of the actual system and an equivalent viscous system. Derive an equation expressing the equivalent viscous damping coefficient for the hysteretic damper, as a function of η, P_0, x, k, m, or other basic parameters identified above.

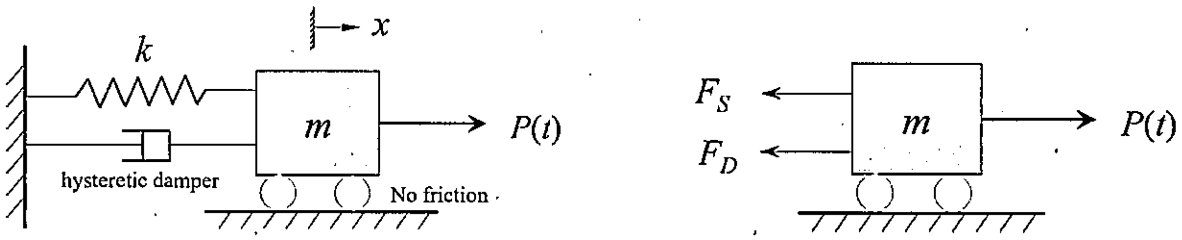
(3) The displacement of the system is X_{st} if it is loaded statically with constant load P_0. Obtain the

value of η necessary for the damper to limit the peak steady-state displacement of the system to three times X_{st} when subjected to $P(t)$.

(4) The behavior of hysteretic damping models given by Eq. 2.2 is considered to be closer to that of real structures than viscous damping models, while viscous damping models are more convenient and simplified for dynamic analysis.

a) Compare the two damping models' energy dissipation performances from a frequency dependence perspective.

b) The viscous damping property of a real structural system could be estimated from its dynamic response obtained from a forced vibration test. Discuss how to obtain the optimal viscous damping coefficient from the test.



(a) basic components (b) forces acting on the mass

Figure 2.1 A single-degree-of-freedom system with a hysteretic damper

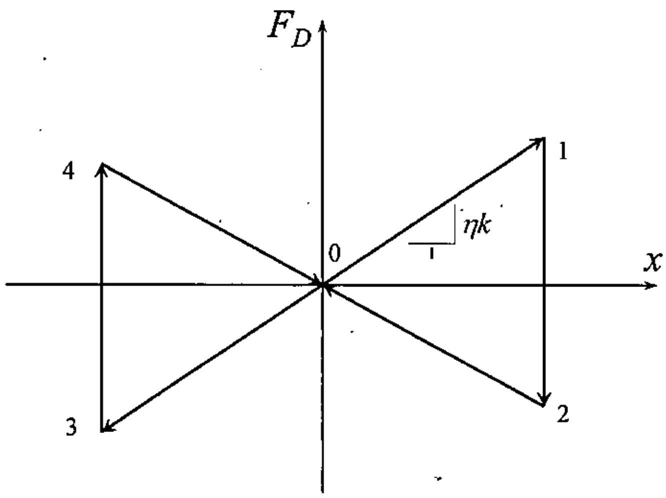


Figure 2.2 Relationship between damping force and displacement under steady-state conditions

hysteretic damper: 履歴型ダンパ, suppress vibration: 振動を抑制する, sinusoidal load: 正弦波荷重, steady-state vibration: 定常振動, angular frequency: 円振動数, viscous damper: 粘性ダンパ, governing equation: 支配方程式, energy dissipation: エネルギー散逸, equivalent viscous damping: 等価粘性減衰, frequency dependence: 振動数依存, forced vibration: 強制振動

分野 2/Field 2: (Concrete Engineering / Geotechnical Engineering)

Question 1

(1) Answer the following questions.

a) In general, the compressive strength of concrete increases as water-to-cement ratio decreases. Explain the reasons based on the microscopic mechanisms in about 3 lines in English or 2 lines in Japanese.

b) Moderate heat Portland cement is often utilized for concrete with low water-to-cement ratio. Explain the reasons based on the clinker composition and chemical reactions in about 4 lines in English or 3 lines in Japanese.

c) Considering the properties of fresh concrete, explain the advantage and disadvantage of increasing the maximum size of coarse aggregate in one line, respectively.

d) Explain what strain hardening of reinforcing steel bars is in one line. Then, explain why strain hardening of reinforcing steel bars is important in the load-bearing performance of steel-reinforced concrete (RC) members in about 4 lines in English or 3 lines in Japanese.

e) Consider an RC slab used in a road structure in a cold region.

- Give an example of combined deterioration caused by two deterioration mechanisms that may occur in the RC slab.
- Discuss mutual interactions between those deterioration mechanisms.
- Then, propose countermeasures to effectively prevent the combined deterioration from the viewpoints of design and maintenance, respectively.

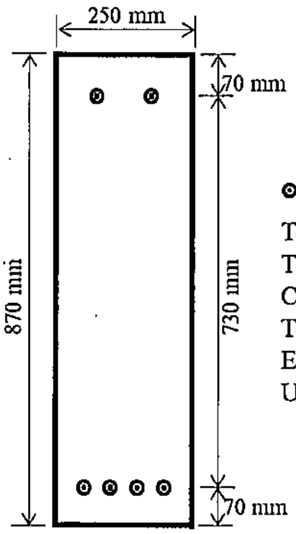
Answer in about 7 lines in English or 5 lines in Japanese in total.

(2) Consider the section of an RC member with properties given in Fig. 1.1, which is subjected to only a flexural moment as an external mechanical load. Answer the following questions. Do not use safety factors.

a) When compressive strength of concrete f'_c is 25 N/mm^2, calculate both the position of the neutral axis and the ultimate flexural capacity (moment) at failure. Show the calculation process when answering the question.

b) Calculate the range of the compressive strength of concrete f'_c which causes yields of both the tensile and compressive reinforcing steel bars when the flexural moment reaches the ultimate flexural capacity.

c) Consider the case where steel corrosion occurs in the RC member. In general, when steel corrosion causes the cross-sectional losses of reinforcing steel bars, the ultimate flexural capacity is often smaller than the one which is calculated simply using the reduced cross-sectional area. Explain the reasons in about 4 lines in English or 3 lines in Japanese.



⊙ indicates reinforcing steel bar

Total cross-sectional area of compressive reinforcements: $A'_s = 2{,}000$ mm^2
Total cross-sectional area of tensile reinforcements: $A_s = 4{,}000$ mm^2
Compressive yield strength of reinforcement: $f'_y = 350$ N/mm^2
Tensile yield strength of reinforcement: $f_y = 350$ N/mm^2
Elastic modulus of reinforcement: $E_s = 200{,}000$ N/mm^2
Ultimate compressive failure strain of concrete: $\varepsilon'_u = 0.0035$

Figure 1.1: Cross section of RC member and material properties

Compressive strength: 圧縮強度, Water-to-cement ratio: 水セメント比, Moderate heat Portland cement: 中庸熱ポルトランドセメント, Clinker composition: クリンカー構成, Chemical reaction: 化学反応, Maximum size of coarse aggregate: 粗骨材最大寸法, Fresh concrete: フレッシュコンクリート, Strain hardening: ひずみ硬化, Reinforcing steel bars (Reinforcements): 補強鉄筋, Load-bearing performance: 耐荷性能, Steel-reinforced concrete member: 鉄筋コンクリート部材, Slab: 床版, Cold Region: 寒冷地, Combined deterioration: 複合劣化, Mutual interactions: 相互作用, Design: 設計, Maintenance: 維持管理, Flexural moment: 曲げモーメント, External mechanical force: 外力, Neutral axis: 中立軸, Ultimate flexural capacity: 曲げ耐力, Service: 供用, Steel Corrosion: 鉄筋腐食, Cross-sectional loss: 断面欠損, Compressive reinforcements: 圧縮側鉄筋, Tensile reinforcements: 引張側鉄筋, Yield strength: 降伏強度, Elastic modulus: 弾性係数, Ultimate compressive failure strain: 圧縮破壊ひずみ.

分野 2/Field 2: (Concrete Engineering / Geotechnical Engineering)

Question 2

(1) Consider the consolidation process illustrated in Fig. 2.1. The soil contained in the tank, of which the bottom is connected to the adjacent pipe, is successively subjected to the following hydraulic conditions from (I) to (V).

(I) At the initial state, the water level of the soil tank is at its surface, and that of the adjacent pipe is also at the same height.

(II) The water levels of the soil tank and the adjacent pipe drops by h meters. Note that the soil above the water level is partially saturated.

(III) Subsequently, the water level of the adjacent pipe is recovered, but the water level of the soil tank is kept.

(IV) An impermeable sheet with negligible thickness and stiffness is inserted at the depth of h meters from the surface of the soil tank.

(V) Subsequently, the water level of the adjacent pipe drops by $(h + D*3/4)$ meters.

Answer the following questions a) and b), assuming one-dimensional consolidation.

a) Express the total stress and pore water pressure at point P for each of the above states from (I) to (V), using h, D, γ_{sat} (the unit weight of saturated soil), γ_t (the wet unit weight of partially saturated soil) and γ_w (the unit weight of water).

b) Calculate the void ratios at point P for each of the above states from (I) to (V), using the values in Table 2.1. Draw the relationship between effective stress and void ratio.

(2) When conducting a laboratory test on soil, we should consider ground conditions and situations during construction. Answer the following questions a), b) and c) regarding the following two cases (I) and (II) on/in ground consisting of a normally consolidated soil, as illustrated in Fig. 2.2.

(I) Point A beneath the foundation subjected to a load

(II) Point B in the backfill ground of underwater excavation

a) What kind of laboratory test is suitable for conservative (safe side) design considering lower strength for each of the constructions (I) and (II), respectively?

b) Explain the reasons for each of the suitable laboratory tests answered in the question a) in about 7 lines in English or 5 lines in Japanese, respectively.

c) Raise effective countermeasures or construction methods for each of the constructions (I) and (II), respectively.

Hydraulic condition: 水理境界条件, Saturated soil: 飽和土, Partially saturated soil: 不飽和土, Impermeable sheet: 不透水シート, One-dimensional consolidation: 一次元圧密, Total stress: 全応力, Pore water pressure: 間隙水圧, Unit weight: 単位体積重量, Effective stress: 有効応力, Void ratio: 間隙比, Compression index: 圧縮指数, Swelling index: 膨潤指数, Consolidation yield stress: 圧密降伏応力, Laboratory test: 室内試験, Conservative (safe side) design: 安全側の設計, Backfill ground: 背面地盤, Underwater excavation: 水中掘削, Failure plane: 破壊面（滑り面）, Sheet pile: 矢板

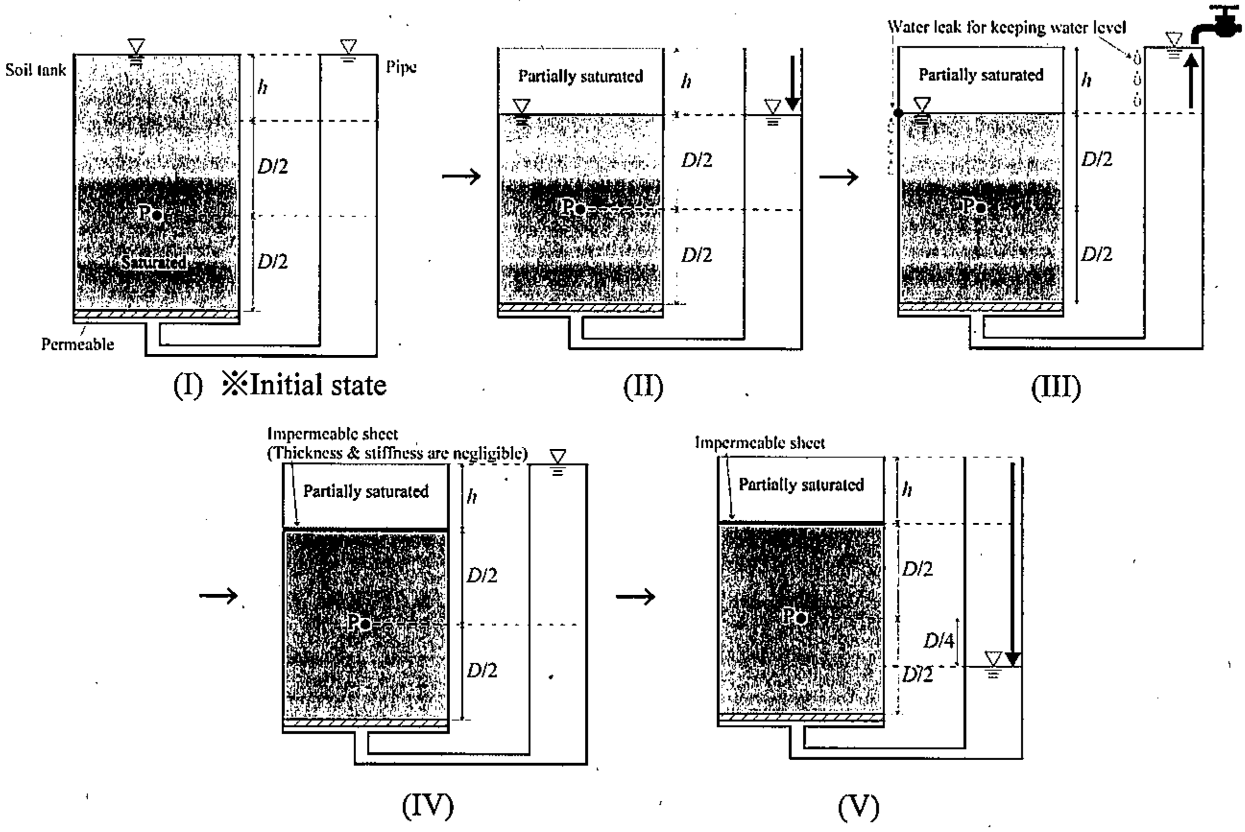


Figure 2.1: Hydraulic conditions of the tank

Table 2.1: Values for calculating the consolidation

γ_{sat}: the unit weight of saturated soil	20.0 kN/m^3	e_0: the initial void ratio	1.0	※Properties at the initial state (I)
γ_t: the wet unit weight of partially saturated soil	16.0 kN/m^3	p_{c0}: the initial consolidation yield stress	90.0 kPa	
C_c: the compression index	1.0	h	3.0 m	Specifications of the soil tank
C_s: the swelling index	0.2	D	10.0 m	
γ_w: the unit weight of water	10.0 kN/m^3			

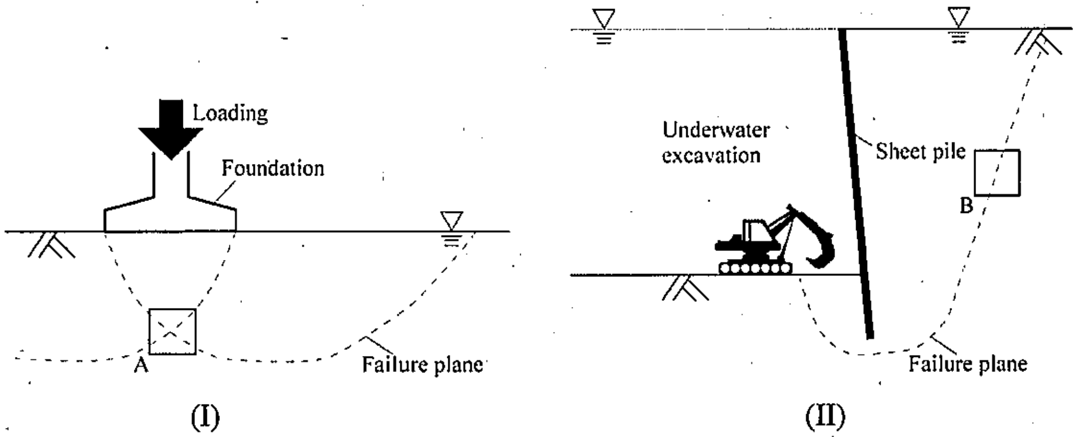


Figure 2.2: Cases (I) and (II) on/in ground consisting of a normally consolidated soil

分野 3/Field 3: (Hydrospheric engineering)

Question 1

Let us consider a 2-dimensional steady flow over a weir of height h_w as shown in Figure 1. The x-axis is horizontal and the z-axis is vertical in the figure. The flow is directed in the positive x-direction. The water depth is $h_1 + h_w$ at the upstream section (Section I), while it is h_2 at the downstream section (Section II). Answer the following questions.

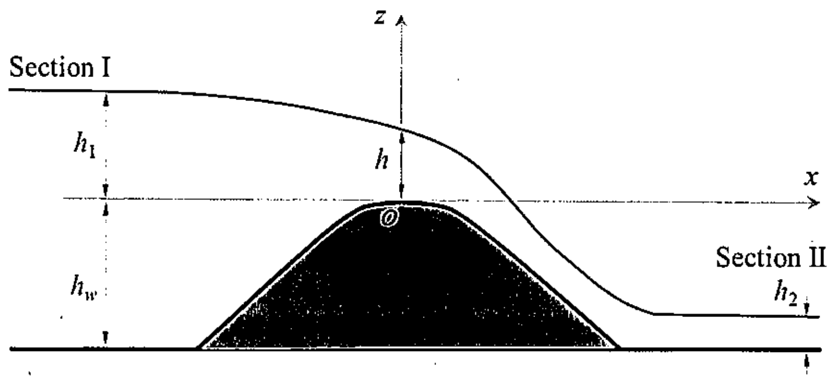


Figure 1: 2-dimensional steady flow over a weir.

(1) The flow discharge per unit width over the weir, q, is given by the following equation under certain assumptions:

$$q = h\sqrt{2g(h_0 - h)} \text{ with } h_0 = h_1 + \frac{V_1^2}{2g}, \qquad [1.1]$$

where g is gravitational acceleration, V_1 is the flow velocity at the Section I, h_0 is the upstream water head, and h is the flow depth on the weir crest as illustrated in Figure 1. Derive Equation [1.1] while clarifying the underlying assumptions.

(2) The flow transits from subcritical to supercritical flow while passing the weir crest. Therefore, the flow state on the weir crest cannot be determined from either upstream or downstream conditions. It is known that, in such situations, the flow depth at the transitional section can be given as follows:

$$h = \frac{2}{3}h_0, \qquad [1.2]$$

which leads Equation [1.1] to a well-known form of the overflow discharge formula:

$$q = \frac{2}{3}\sqrt{\frac{2}{3}gh_0^3}, \qquad [1.3]$$

a) Explain the above underlined sentence; why cannot it be determined?
b) Describe the theoretical basis of Equation [1.2].

(3) It is more convenient and practical to express the discharge formula in terms of the upstream water level h_1 which is directly measurable. Therefore, we often approximate Equation [1.3] as follows:

$$q = \frac{2}{3}\sqrt{\frac{2}{3}gh_1^3}, \qquad [1.4]$$

a) Explain a condition of h_1 under which this approximation works well.

b) Estimate the percentage error in q associated with this approximation when $h_1 = h_w$.

(4) The accuracy of the discharge formula above is restricted by the assumptions on which Equation [1.1] is based. Therefore, in practice, we need to introduce the discharge coefficient, c_d, into Equation [1.4] as follows:

$$q = \frac{2}{3}c_d\sqrt{\frac{2}{3}gh_1^3}, \qquad [1.5]$$

Laboratory tests have been conducted by many researchers to determine c_d for weirs of different geometries. One of the most restrictive assumptions is that the water pressure on the weir crest is hydrostatic.

a) Demonstrate that the pressure distribution on the weir crest generally differs from the hydrostatic one using Euler's equations of motion.

b) Discuss how the effect of the non-hydrostatic pressure on c_d varies with the weir shape.

(5) The design of a weir requires evaluating the horizontal forces generated by the flow.

a) Express the total horizontal force per unit width using ρ, g, h_w, h_1 and h_2 when $c_d = 1$, where ρ is density of water. You may neglect tangential forces on the weir surface.

b) Discuss the validity of the approximation of neglecting the tangential forces.

steady flow: 定常流れ, weir: 堰, crest: 天端, flow discharge: 流量, subcritical flow: 常流, supercritical flow: 射流, transitional: 遷移する, overflow discharge formula: 越流公式, hydrostatic: 静水状態の, non-hydrostatic: 非静水状態の, Euler's equations of motion：オイラーの運動方程式, tangential force：面に沿う方向の力

分野 3/Field 3: (Hydrospheric engineering)

Question 2

Read the following description about the velocity profile of an open channel flow and answer all the following questions. You may define variables and parameters if necessary. Show processes that led to your solution.

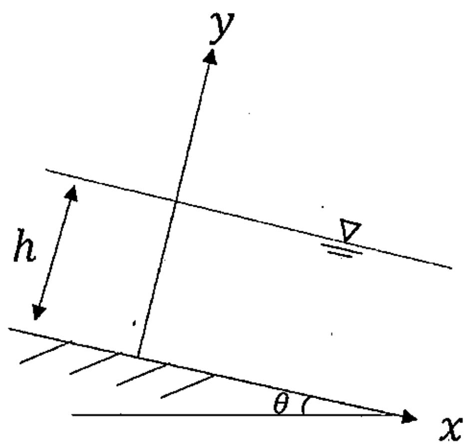


Figure 2: 2-dimensional open channel flow.

Let's discuss the velocity profile of a 2-dimensional steady and uniform open channel flow with the depth h and the gradient θ as a model of a river (see Figure 2). The 2-dimensional Navier-Stokes equation can be written as:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = gI - \frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right), \quad [2.1]$$

where u is velocity in x-direction, v is velocity in y-direction, g is gravitational acceleration, $I = \sin\theta$ is slope of the riverbed, ρ is density of water, P is pressure, μ is viscosity coefficient, x is axis along the river, y is the distance from the riverbed, and t is time.

<u>Equation [2.1] includes the contribution of molecular viscosity stress</u> (1). <u>When Reynolds number is small and a laminar flow can be assumed, the velocity profile can be obtained by solving Equation [2.1]</u> (2). However, to consider a realistic river flow, it is necessary to include the effect of turbulence. The variables in [2.1] are decomposed into ensemble means $(\bar{u}, \bar{v}, \bar{P})$ and fluctuations (u', v', P'):

$$u = \bar{u} + u', v = \bar{v} + v', P = \bar{P} + P'. \quad [2.2]$$

Then, the 2-dimensional Reynolds equation can be written as:

$$\frac{\partial \bar{u}}{\partial t} + \bar{u}\frac{\partial \bar{u}}{\partial x} + \bar{v}\frac{\partial \bar{u}}{\partial y} = gI - \frac{1}{\rho}\frac{\partial \bar{P}}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 \bar{u}}{\partial x^2} + \frac{\partial^2 \bar{u}}{\partial y^2}\right) - \left(\frac{\partial \overline{u'^2}}{\partial x} + \frac{\partial \overline{u'v'}}{\partial y}\right). \quad [2.3]$$

Equation [2.3] includes the contribution of turbulence. Although the ensemble means of the fluctuating components of velocity are zero (e.g., $\overline{u'} = 0$), the fluctuating components affect the mean flow velocity, $\bar{u}$ and $\bar{v}$. (3) In the model of a realistic river flow, the molecular viscosity term in [2.3] can be neglected except for the thin viscous sublayer. (4) In this case, Equation [2.3] can be solved for the steady and uniform flow by applying the mixing length model to parameterize Reynolds stress:

$$-\rho\overline{u'v'} = \rho l^2 \left|\frac{d\bar{u}}{dy}\right| \frac{d\bar{u}}{dy}, \quad l = \kappa y, \qquad [2.4]$$

where l is mixing length, κ is Karman coefficient.

The velocity profile obtained in this way can be empirically applied in all depths except for the viscous sublayer. This velocity profile can explain that the existing empirical equations of depth-averaged velocity such as the Chézy equation shown in [2.5] are reasonable approximation: (5)

$$U = C\sqrt{RI}, \qquad [2.5]$$

where U is depth-averaged velocity, C is Chézy coefficient, and R is hydraulic radius. The consideration of turbulence is extremely important to accurately estimate velocity profile and discharge.

Turbulence also plays an important role in sediment transport in river basins. (6) Furthermore, turbulence in boundary layers substantially affects global water cycles. (7) Thus, it is necessary to consider turbulent flows to estimate basin-scale water budgets. Therefore, modeling turbulence is extremely important for integrated water resources management.

(1) a) Which term in Equation [2.1] indicates the contribution of molecular viscosity stress?

b) In some fluids, molecular viscosity stress does not follow the answer of 1a). Discuss what characteristic of a fluid is necessary to formulate the contribution of molecular viscosity stress as the answer of 1a).

c) Provide an example of fluids whose contributions of molecular viscosity stress cannot be formulated as the answer of 1a).

(2) Solve Equation [2.1] for the steady and uniform flow and derive velocity profile $u(y)$. As boundary conditions, use non-slip condition at the bed $(y = 0)$ and assume no molecular viscosity stress at the water surface $(y = h)$.

(3) Using Equations [2.1] and [2.2], derive Equation [2.3]. Discuss why the fluctuating components of velocity affect the mean flow velocity, $\bar{u}$ and $\bar{v}$.

(4) Discuss what affects the existence and thickness of the viscous sublayer in a river.

(5) a) Solve Equation [2.3] for the steady and uniform flow and derive velocity profile $\bar{u}(y)$ by neglecting molecular viscosity stress and parameterizing Reynolds stress by Equation [2.4]. As the boundary condition, assume no Reynolds stress at the water surface ($y = h$). You may also assume $y \ll h$.

b) By deriving the depth-averaged velocity from your answer of 5a), discuss the relationship between your answer of 5a) and the Chézy equation [2.5].

(6) Discuss why turbulence in boundary layers is important for sediment transport in river basins. Answer in 1-2 lines.

(7) Discuss why turbulence in boundary layers is important for global water cycles. Answer in 3-5 lines.

velocity profile: 流速分布, steady and uniform open channel flow: 定常な開水路等流,
Navier-Stokes equation: ナビエストークス方程式, viscosity coefficient: 粘性係数,
riverbed: 河床, molecular viscosity stress: 分子粘性応力, Reynolds number: レイノルズ数,
laminar flow: 層流, turbulence: 乱流, ensemble means: アンサンブル平均,
fluctuations: 変動成分, Reynolds equation: レイノルズ方程式, viscous sublayer: 粘性底層,
mixing length model: 混合距離モデル, Reynolds stress: レイノルズ応力,
mixing length: 混合距離, Karman coefficient: カルマン定数,
depth-averaged velocity: 水深平均流速, Chézy equation: シェジーの式,
hydraulic radius: 径深, sediment transport: 堆積物輸送, boundary layers: 境界層,
water budgets: 水収支, non-slip condition: ノンスリップ条件

分野 4 / Field 4 (Transportation / Spatial information engineering):

Question 1

Answer the following questions.

(1) Draw a triangular fundamental diagram of traffic flow with traffic density k [veh/km] as the horizontal axis and traffic flow q [veh/h] as the vertical axis according to the following conditions:

- The wave speed in uncongested traffic is 60 [km/h].
- The wave speed in congested traffic is -20 [km/h].
- The maximum throughput is $2{,}400$ [veh/h].

(2) Consider an activity combination that maximizes the sum of utilities of the activities conducted during the time constraint. Find all the combination of activities maximizing the sum of utilities using a search tree and the branch-and-bound method, and show the calculation process. The utility and consumed time for each candidate activity are shown in Table 1.1. The total consumed time should not exceed 9 hours.

Table 1.1.: Candidate activities

	Activity	Utility	Consumed time [h]
A	Shopping for luxury	5	3
B	Shopping for daily use	3	2
C	Exercise	10	6
D	Meeting people	7	4
E	Watching a movie	8	5

(3) Suppose a major landslide severely damages the railroad network between the business district and the commuter suburb in a regional metropolitan area as shown in Fig. 1.1. There is no rail network to bypass the damaged section. To reach the business district, the residents in the commuter suburb must travel on the roads that have already been restored. Since road congestion would be severe if all commuters use their cars, the railroad operator and the local government cooperate to operate a free temporary bus service for railroad users. Obviously, the temporary bus service will help the residents who do not own cars.

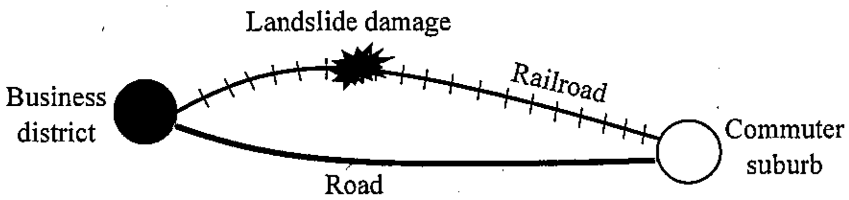


Figure 1.1.: Connection between the business district and the commuter suburb

a) Raise two measures that can be adopted to promote the use of temporary buses, and explain their strengths and weaknesses, in about 4 lines in English or 3 lines in Japanese for each measure.

b) Raise traffic management measures to reduce congestion other than the free temporary bus service, and explain their strengths and weaknesses, in about 4 lines in English or 3 lines in Japanese.

Traffic density: 交通密度, Traffic flow: 交通流率, Uncongested traffic: 非渋滞時, Congested traffic: 渋滞時, Maximum throughput: 最大スループット,
Time constraint: 時間制約, Combination of activities: 活動の組み合わせ, Search tree: 探索木, Branch-and-bound method: 分枝限定法, Utility: 効用, Time consumed: 消費時間,
Landslide: 土砂災害, Business district: 業務地, Commuter suburb: ベッドタウン, Regional metropolitan areas: 地方都市圏, Road congestion: 道路渋滞, Free temporary bus service: 無料の臨時バスサービス

分野 4 / Field 4 (Transportation / Spatial information engineering):

Question 2

(1) Answer the following questions about spatial information technologies.

a) Explain the principle of single point positioning GPS considering the contents of satellite messages and processing of receiver, each in about six lines in English or five lines in Japanese.

b) The web map tile technology becomes so popular due to smooth operability. Explain the most advantageous point of the map tile system for web map service providers in about six lines in English or five lines in Japanese.

(2) Consider the conversion of annual raw GPS data of millions of people to individual trip data for easier querying. Explain main steps involved and their processing algorithms in about 12 lines in English or 10 lines in Japanese in total.

(3) Recently emergence of deep learning enables us to have high accuracy of object recognition with training data. Draw the network diagram and calculate the number of parameters required for deep learning using a CNN (Convolutional Neural Network) to make a binary decision (for example, given image contains urban area or not) from three RGB channels when the input image is 512× 512 pixels. The CNN settings shall be as follows.

a) Three convolutional layers

Filter size: 5×5

The number of filters: 64, 128 and 256 with three layers

Stride: one pixel

Padding type: zero padding

b) Three pooling layers

Filter size: 2×2

The number of filters: three layers after convolutional layers each

Type: max pooling

Stride: two pixels

Padding type: zero padding

c) Dense layer

Hidden layer of 256 neurons

Single point positioning: 単独測位, Satellite message: 衛星信号, Map tile technology: 地図タイル技術, Raw GPS data: 処理前の生の GPS データ, Convolutional Neural Networks: 畳込みニューラルネットワーク, Pooling layer: プーリング層, Dense layer: 圧縮層

分野 5/Field 5: (Urban / Landscape)

Question 1

(1) Fig. 1.1. shows a railroad plan of Tokyo at around 1900. The solid lines show existing railroads and the dashed lines show proposed railroads. Explain the backgrounds and (railroad operators' and government's) intentions of the railroad plan, within about 10 lines in English or 7 lines in Japanese.

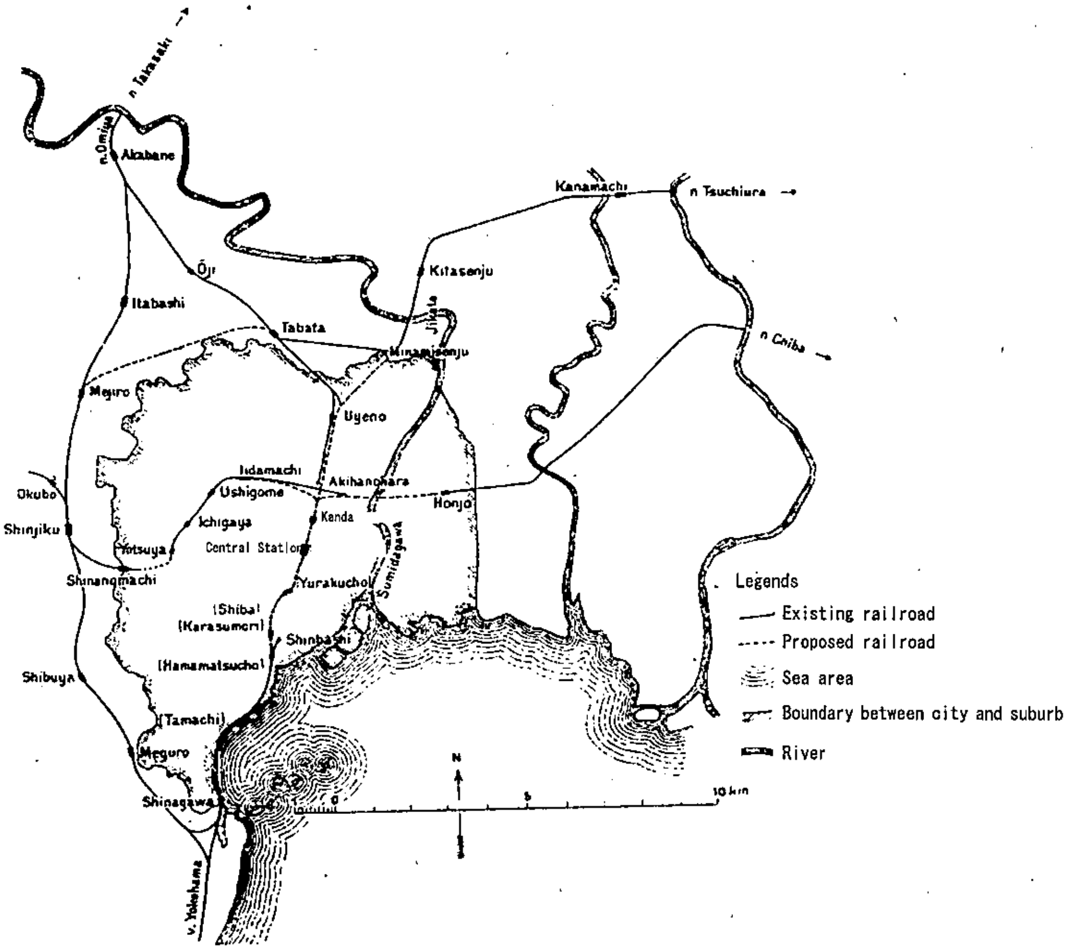


Figure 1.1.: Railroad plan in Tokyo (Partly revised)

(2) Tokyo Station has been the terminal and central station of the Tokyo metropolitan area since its opening in 1914. Discuss the future roles of Tokyo Station and its surrounding area, considering the possibilities of developing information and communication technology and opening the Maglev bullet train from Shinagawa station, in about 13 lines in English or 10 lines in Japanese.

Railroad plan: 鉄道計画図, Maglev bullet train: リニア新幹線,

Information and communication technology: 情報通信技術

分野 5/Field 5: (Urban / Landscape)

Question 2

Garrett Eckbo, a famous American landscape architect in the 20th century, gives his opinion on the quality of the landscape in the following extract from his work “The Landscape We See”. Answer the following questions related to this text.

Quantitatively the landscape is total; it includes everything we see wherever we are. Qualitatively, however, is a different matter. We see? Who sees? Quality does not reside in the scene, nor does it reside in the observer. It resides precisely in the relationship which exists at a given time between the two. This is the design problem for all who are concerned with the quality of the landscape.

[…]

By *quality* I mean a relationship between an individual or a group of people and a landscape. This relationship involves human perception, comprehension, and reaction as a process which measures quality. The essence of landscape quality is neither in the landscape itself nor in people, but rather in the nature of the relationships which are established between them.

(G. Eckbo, *The Landscape We See*, 1969; partly revised)

A Japanese translation：

量として扱うなら、景観とは、どこであれその場所から見えるあらゆるものの総和である。しかし質を問うなら別の話になる。見える？だれが見るかによって見えるものはちがうのだ。質が宿るのはシーンのなかではないし、それを眺める観察者のなかでもない。正しくは、ある時点において両者のあいだに現出している関係のうちに、宿るのである。それこそが、景観の質に関心を寄せるすべての人にとっての、デザイン上の問題である。

［中略］

「質」という言葉でわたしが言いたいのは、ある個人もしくはある一群の人々と景観とのあいだの、関係のことである。この関係によって、景観の質を判定する一連の過程である、人間の認識、理解、反応が引き起こされるのである。景観の質の根源は、景観それ自体にあるのでも、人々にあるのでもない。むしろ、景観と人々とのあいだに築かれる関係に備わっている性質のなかにある。

(1) As G. Eckbo says, the quality of the landscape depends on the relationship between the scene and the observer, primarily the spatial relationship between visual targets and the viewpoint.

a) List two indicators for the spatial relationship between visual targets and the viewpoint and explain them briefly, within three lines in English or two lines in Japanese each.

b) Give an example of the landscape which is generated by intentionally creating spatial relationship between visual targets and the viewpoint, within eight lines in English or five lines in Japanese. You may use visual aids such as diagrams or sketches, if necessary.

(2) From G. Eckbo's point of view, we can say that "good" landscape design is to produce some qualities which bring us better human perception, comprehension, and reaction by creating or improving relationships between people and landscape. Give an example of what you think "good" landscape design in this sense and describe it, within fifteen lines in English or ten lines in Japanese. You may use visual aids such as diagrams or sketches, if necessary.

indicators for the spatial relationship between visual targets and the viewpoint：視対象と視点の空間的関係を表す指標

the landscape which is generated by intentionally creating spatial relationship：空間的関係を意図して創出することにより生み出された景観

分野 6/Field 6: (International Project / Management)

Question 1

Construction projects typically involve a wide range of risks, such as unforeseen site conditions, natural disasters and market price inflation. A contract is often considered as a tool for risk management, allocating each risk factor to one or more project parties.

Answer all the following questions. All answers should fit within a maximum of 2 pages.

(1) Discuss issues concerning the standard 'lump sum' construction contracts from the viewpoint of risk management.

(2) Choose one project risk factor, and discuss what contractual arrangements can effectively address the risk factor chosen. You may refer not only to the construction stage, but also to other related project stages, including design, pre-construction and post-construction.

Unforeseen site conditions: 予期しない現場条件

Market price inflation: 市場価格高騰

Project party: 事業関係主体

'Lump sum' contract: 総価請負契約

Contractual arrangements: 契約上の取り決め

分野 6/Field 6: International Project / Management

Question 2

Read the following text and answer the four questions below.

"Despite the global poverty rate having been halved since 2000, almost one billion people are still living without access to reliable and affordable electricity. A lack of access to modern energy impacts health and welfare and impedes sustainable development.(A) Knowing the location of those one billion is crucial if aid and infrastructure are to reach them. Traditionally, wealth and poverty have been measured through surveys of household income and consumption. However, many developing countries, particularly in sub-Saharan Africa, have only rudimentary economic statistics, and in many cases, lack regional data.(B) The international donor community is attempting to address poverty by spending billions of dollars annually in aid for the world's poorest countries based on the assumption that aid is flowing to where poor people live.

(...)

Given the paucity of relevant information, one of the most promising methods for estimating economic activity—especially for countries with low-quality statistical systems—is that of satellite-derived radiance.(C)"

(1) Regarding the underlined part (A), how does the access to modern energy impact poverty? Explain the mechanism within four lines in English or three lines in Japanese.

(2) Regarding the underlined part (B), why do many developing countries suffer from poor availability of regional data? Raise three reasons and describe them within three lines in English or two lines in Japanese for each.

(3) Regarding the underlined part (C), why is the satellite-derived radiance a promising method for estimating economic activity from a viewpoint of the international donor community? Raise three reasons and describe them within three lines in English or two lines in Japanese for each.

(4) As stated in the above text, the satellite-derived radiance has been often used for analyzing regional economic activities. Suppose that you would use the global satellite nighttime light data for post-evaluation of the impacts of a seaport investment on regional economies. Explain an appropriate method for this post-evaluation within eight lines in English or six lines in Japanese.

affordable： 購入しやすい， impede： 妨げる， rudimentary: 初歩的な，
paucity：不足， satellite-derived： 人工衛星由来の， radiance：輝き，
post-evaluation：事後評価， nighttime light：夜間光

「社会基盤学」問題冊子
Question Booklet of "Civil Engineering"

2023 年度　大学院入試
東京大学大学院工学系研究科社会基盤学専攻　博士課程

The 2023 Entrance Examination
Doctoral program, Department of Civil Engineering,
Graduate School of Engineering, The University of Tokyo

2022 年 8 月 29 日（月）　9:00 – 10:30（日本時間）
August 29th, 2022 (Monday) 9:00 – 10:30 (in JST)

分野 1 (Field 1)　構造・設計 (Structures / Design)
分野 2 (Field 2)　材料・地盤 (Concrete engineering / Geotechnical engineering)
分野 3 (Field 3)　水圏工学 (Hydrospheric engineering)
分野 4 (Field 4)　交通・空間情報 (Transportation / Spatial information engineering)
分野 5 (Field 5)　都市・景観 (Urban / Landscape)
分野 6 (Field 6)　国際プロジェクト・マネジメント (International project / Management)

注意事項 / Notices

- 日本語もしくは英語で、手書きで解答すること。Answers must be handwritten in Japanese or English.
- 事前に申告した１分野に対して解答すること。申告と異なる分野の回答は採点されません。Answer the questions in the one exam field which you have selected in advance. If you answer questions in exam field different from your selection, your answers will not be scored.
- 分野ごとに、指定された解答用紙を使用してください。Please use the designated answer sheets for each exam field.
- すべての解答用紙の受験番号欄に受験番号を記入してください。Please fill your examinee number for all the answer sheets.
- 本試験はオープンブック形式の試験です。インターネットを含め、ノートや参考書を使用しても構いません。Examinees are permitted to refer to any documents including materials on the website to answer the questions (Open book style).
- 試験終了後、分野ごとに解答用紙を指定されたサイトにアップロードしてください。白紙答案の場合も、アップロードは必要です。After the exam, please upload your answer sheets for each exam field to the designated website. You need to upload your answer sheets even if they are blank.
- 試験終了後、解答用紙は速達書留で社会基盤学専攻に郵送してください。Answer sheets should be mailed to the Department of Civil Engineering, University of Tokyo by postal mail using registered express mail.

分野 1 /Field 1 (Structures / Design)

Question 1

Fig. 1.1 shows a cantilever beam subjected to a point load P. The beam is made of a linear elastic material with the Young's modulus E, and has the sectional area $A = 2h \times b$. w is the bending induced downward displacement of the beam. Answer all the following questions assuming that the deformations are infinitesimally small, and the Euler-Bernoulli beam theory (i.e., simple beam theory) is valid for this beam.

(1) Consider the bending induced deformation of the beam segment of infinitesimal length dx shown in Fig. 1.2(b). The radius of curvature of the neutral plane of the deformed beam segment is R. Obtain expressions for the axial strain, ϵ, and stress, σ, of a fiber located y distance from the neutral plane when the ends are subjected to a moment M.

(2) Obtain an expression for the bending induced elastic energy, $H = \frac{1}{2}\int_V \sigma\epsilon \, dV$, of the beam in terms of I, E and R, where V is the volume of the beam, I is the second moment of the area, and $\frac{1}{R} = \frac{d^2w}{dx^2}$.

(3) For the cantilever beam shown in Fig. 1.1, w can be approximated as $w = \alpha x^3 + \beta x^2$, where α and β are constants. Let $\Delta H = H - W$, where H is the elastic energy stored in the system and W is the work done by the force P. $W = Pw(L)$, where $w(L)$ is the displacement at $x = L$. Find α and β by minimizing ΔH with respect to α and β (i.e., by setting $\frac{\partial \Delta H}{\partial \alpha} = 0$ and $\frac{\partial \Delta H}{\partial \beta} = 0$).

(4) In addition to bending moments, shear forces also contribute to the deformation of beams. The shear induced downward displacement u (see Fig. 1.2(c)) of a beam can be approximately estimated using the differential equation $G\frac{du}{dx} = \frac{P}{A}$, where $G = \frac{E}{2(1+\nu)}$ is the shear modulus and ν is the Poisson's ratio.

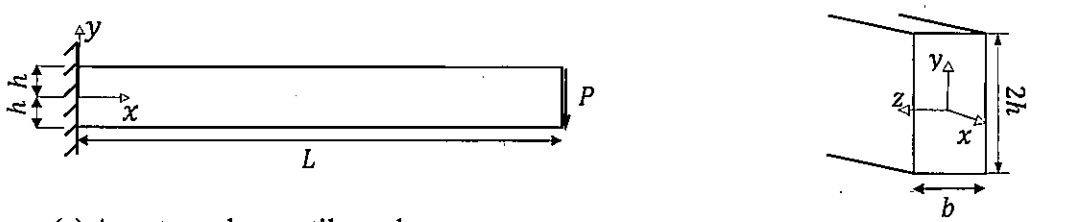
a) Find the shear induced deformation, u, of the beam shown in Fig. 1.1 as a function of x.

b) Prove that the shear induced deformation of the cantilever beam shown in Fig. 1.1 is negligibly small compared to bending induced deformation (i.e., $u \ll w$).

(5) Consider that the left end of the beam is connected to a linear rotational spring of stiffness k as shown in Fig. 1.3. The geometric and material properties of the beam are identical to those of the beam shown in Fig. 1.1. Ignore any shear induced deformations.

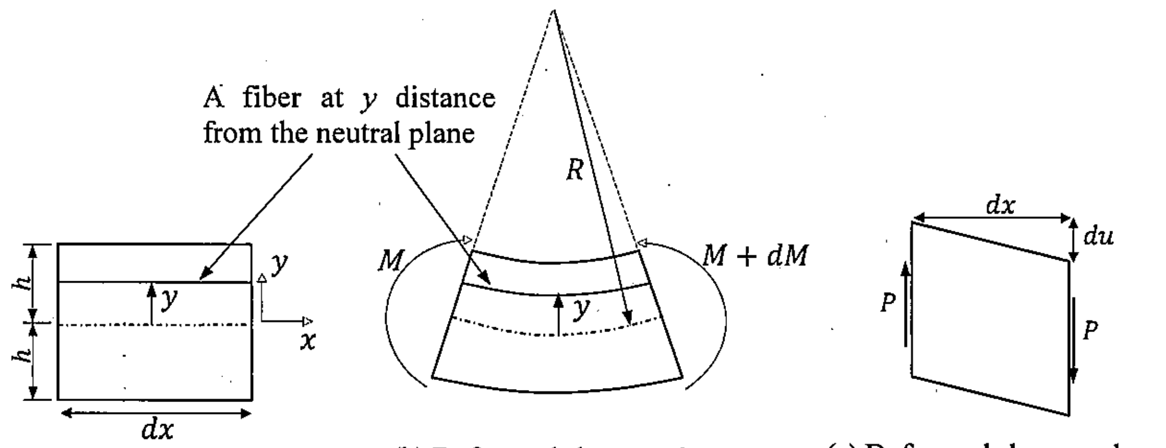
a) Write an expression for the $\Delta H' = H' - W'$ of the new system, where H' is the elastic energy stored in the new system and W' is the new work done by force P.
b) Propose a suitable polynomial to approximate the new downward deformation, w', of the beam. Briefly explain the reasons for your choice of the approximation.
c) Find the unknown coefficients of the polynomial you proposed.

cantilever beam: 片持ち梁, Young's modulus: ヤング率, infinitesimally small: 無限小, Euler-Bernoulli beam theory: ベルヌーイ・オイラー梁理論, radius of curvature: 曲率半径, neutral plane: 中立面, elastic energy: 弾性エネルギー, second moment of area: 断面二次モーメント, downward displacement: 下方変位, rotational spring: 回転バネ, polynomial: 多項式, shear modulus: せん断弾性率



(a) A rectangular cantilever beam (b) Cross-section

Figure 1.1: A rectangular beam with cross sectional dimensions $2h \times b$, and length L.



(a) Undeformed shape (b) Deformed shape under a bending moment M (c) Deformed shape under a shear force P

Figure 1.2: Undeformed and deformed shapes of an infinitesimal beam segment of length dx when subjected to a bending moment M and shear force P.

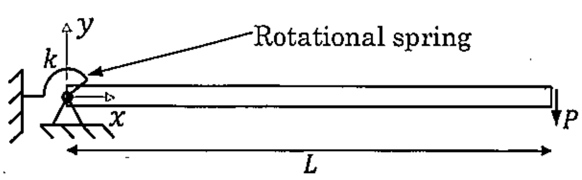


Figure 1.3: A beam connected to a rotational spring.

分野 1 /Field 1: (Structures / Design)

Question 2

Fig. 2.1(a) shows a newly developed hysteretic damper utilized to suppress the vibration of a single-degree-of-freedom system. The system is subjected to a sinusoidal load $P(t)$ that induces the steady-state vibration. The load is defined as Eq. 2.1.

$$P(t) = P_0 \sin(\omega t) \tag{2.1}$$

Here, P_0 is a constant and ω is the angular frequency. k and m are the stiffness and mass of the system in which the damper is installed. Let t denote time. The displacement of the mass is $x(t)$. Fig. 2.1(b) shows the forces acting on the mass including the elastic resistance force F_S, the damping force F_D, and $P(t)$. For this damper, the relationship between the damping force F_D and the displacement x under steady-state conditions is shown in Fig. 2.2. Starting from the origin 0, the cycle continues to point 1, point 2, point 0, point 3, point 4, and finally returns to the origin. This relationship can be mathematically described as Eq. 2.2.

$$F_D = \eta k |x| \operatorname{sgn}(\dot{x}) \tag{2.2}$$

Here, the parameter η is a property of the damper assignable by the designer and $\operatorname{sgn}(\dot{x})$ is defined as Eq. 2.3.

$$\operatorname{sgn}(\dot{x}) = \begin{cases} -1 & \text{for } \dot{x} < 0 \\ 0 & \text{for } \dot{x} = 0 \\ 1 & \text{for } \dot{x} > 0 \end{cases} \tag{2.3}$$

In dynamics, damping is usually represented by viscous damping, which is the simplest form of damping since the governing differential equation of motion is linear. Assuming this hysteretic damper could be approximated by an equivalent viscous damper, answer the following questions.

(1) The damper dissipates the vibration energy E_D, which can be calculated by the work done by the damping force, i.e., $E_D = \int F_D dx$. Let x_0 denote the maximum displacement of the mass. Obtain the energy dissipation by the hysteretic damper during one cycle of the motion.

(2) The most common method for defining equivalent viscous damping is to equate the energy dissipated in a vibration cycle of the actual system and an equivalent viscous system. Derive an equation expressing the equivalent viscous damping coefficient for the hysteretic damper, as a function of η, P_0, x, k, m, or other basic parameters identified above.

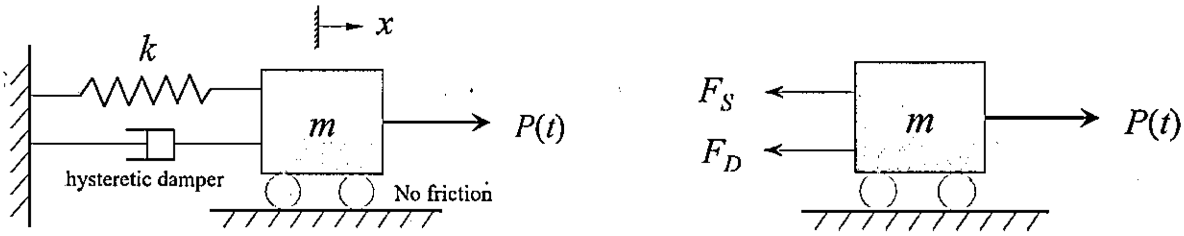
(3) The displacement of the system is X_{st} if it is loaded statically with constant load P_0. Obtain the

value of η necessary for the damper to limit the peak steady-state displacement of the system to three times X_{st} when subjected to $P(t)$.

(4) The behavior of hysteretic damping models given by Eq. 2.2 is considered to be closer to that of real structures than viscous damping models, while viscous damping models are more convenient and simplified for dynamic analysis.

a) Compare the two damping models' energy dissipation performances from a frequency dependence perspective.

b) The viscous damping property of a real structural system could be estimated from its dynamic response obtained from a forced vibration test. Discuss how to obtain the optimal viscous damping coefficient from the test.



(a) basic components (b) forces acting on the mass

Figure 2.1 A single-degree-of-freedom system with a hysteretic damper

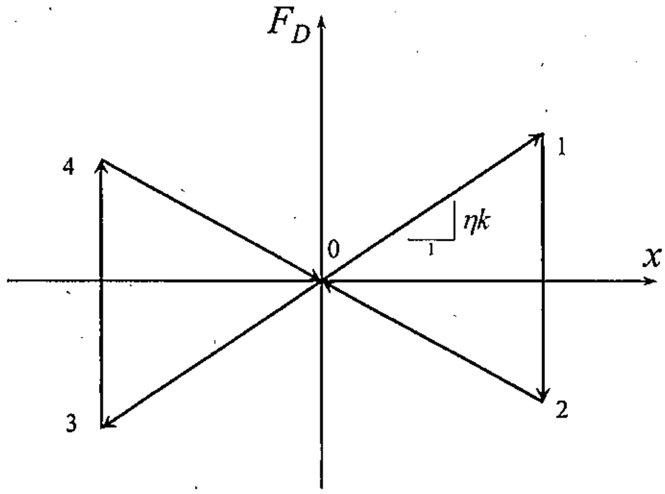


Figure 2.2 Relationship between damping force and displacement under steady-state conditions

hysteretic damper: 履歴型ダンパ, suppress vibration: 振動を抑制する, sinusoidal load: 正弦波荷重, steady-state vibration: 定常振動, angular frequency: 円振動数, viscous damper: 粘性ダンパ, governing equation: 支配方程式, energy dissipation: エネルギー散逸, equivalent viscous damping: 等価粘性減衰, frequency dependence: 振動数依存, forced vibration: 強制振動

分野 2/Field 2: (Concrete Engineering / Geotechnical Engineering)

Question 1

(1) Answer the following questions.

a) In general, the compressive strength of concrete increases as water-to-cement ratio decreases. Explain the reasons based on the microscopic mechanisms in about 3 lines in English or 2 lines in Japanese.

b) Moderate heat Portland cement is often utilized for concrete with low water-to-cement ratio. Explain the reasons based on the clinker composition and chemical reactions in about 4 lines in English or 3 lines in Japanese.

c) Considering the properties of fresh concrete, explain the advantage and disadvantage of increasing the maximum size of coarse aggregate in one line, respectively.

d) Explain what strain hardening of reinforcing steel bars is in one line. Then, explain why strain hardening of reinforcing steel bars is important in the load-bearing performance of steel-reinforced concrete (RC) members in about 4 lines in English or 3 lines in Japanese.

e) Consider an RC slab used in a road structure in a cold region.

- Give an example of combined deterioration caused by two deterioration mechanisms that may occur in the RC slab.
- Discuss mutual interactions between those deterioration mechanisms.
- Then, propose countermeasures to effectively prevent the combined deterioration from the viewpoints of design and maintenance, respectively.

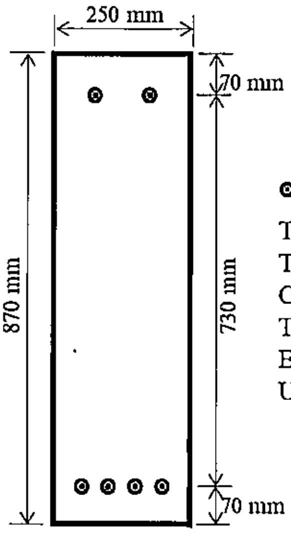
Answer in about 7 lines in English or 5 lines in Japanese in total.

(2) Consider the section of an RC member with properties given in Fig. 1.1, which is subjected to only a flexural moment as an external mechanical load. Answer the following questions. Do not use safety factors.

a) When compressive strength of concrete f'_c is 25 N/mm^2, calculate both the position of the neutral axis and the ultimate flexural capacity (moment) at failure. Show the calculation process when answering the question.

b) Calculate the range of the compressive strength of concrete f'_c which causes yields of both the tensile and compressive reinforcing steel bars when the flexural moment reaches the ultimate flexural capacity.

c) Consider the case where steel corrosion occurs in the RC member. In general, when steel corrosion causes the cross-sectional losses of reinforcing steel bars, the ultimate flexural capacity is often smaller than the one which is calculated simply using the reduced cross-sectional area. Explain the reasons in about 4 lines in English or 3 lines in Japanese.



◎ indicates reinforcing steel bar

Total cross-sectional area of compressive reinforcements: $A'_s = 2{,}000$ mm^2
Total cross-sectional area of tensile reinforcements: $A_s = 4{,}000$ mm^2
Compressive yield strength of reinforcement: $f'_y = 350$ N/mm^2
Tensile yield strength of reinforcement: $f_y = 350$ N/mm^2
Elastic modulus of reinforcement: $E_s = 200{,}000$ N/mm^2
Ultimate compressive failure strain of concrete: $\varepsilon'_u = 0.0035$

Figure 1.1: Cross section of RC member and material properties

Compressive strength: 圧縮強度, Water-to-cement ratio: 水セメント比, Moderate heat Portland cement: 中庸熱ポルトランドセメント, Clinker composition: クリンカー構成, Chemical reaction: 化学反応, Maximum size of coarse aggregate: 粗骨材最大寸法, Fresh concrete: フレッシュコンクリート, Strain hardening: ひずみ硬化, Reinforcing steel bars (Reinforcements): 補強鉄筋, Load-bearing performance: 耐荷性能, Steel-reinforced concrete member: 鉄筋コンクリート部材, Slab: 床版, Cold Region: 寒冷地, Combined deterioration: 複合劣化, Mutual interactions: 相互作用, Design: 設計, Maintenance: 維持管理, Flexural moment: 曲げモーメント, External mechanical force: 外力, Neutral axis: 中立軸, Ultimate flexural capacity: 曲げ耐力, Service: 供用, Steel Corrosion: 鉄筋腐食, Cross-sectional loss: 断面欠損, Compressive reinforcements: 圧縮側鉄筋, Tensile reinforcements: 引張側鉄筋, Yield strength: 降伏強度, Elastic modulus: 弾性係数, Ultimate compressive failure strain: 圧縮破壊ひずみ.

分野 2/Field 2: (Concrete Engineering / Geotechnical Engineering)

Question 2

(1) Consider the consolidation process illustrated in Fig. 2.1. The soil contained in the tank, of which the bottom is connected to the adjacent pipe, is successively subjected to the following hydraulic conditions from (I) to (V).

(I) At the initial state, the water level of the soil tank is at its surface, and that of the adjacent pipe is also at the same height.

(II) The water levels of the soil tank and the adjacent pipe drops by *h* meters. Note that the soil above the water level is partially saturated.

(III) Subsequently, the water level of the adjacent pipe is recovered, but the water level of the soil tank is kept.

(IV) An impermeable sheet with negligible thickness and stiffness is inserted at the depth of *h* meters from the surface of the soil tank.

(V) Subsequently, the water level of the adjacent pipe drops by ($h + D*3/4$) meters.

Answer the following questions a) and b), assuming one-dimensional consolidation.

a) Express the total stress and pore water pressure at point P for each of the above states from (I) to (V), using h, D, γ_{sat} (the unit weight of saturated soil), γ_t (the wet unit weight of partially saturated soil) and γ_w (the unit weight of water).

b) Calculate the void ratios at point P for each of the above states from (I) to (V), using the values in Table 2.1. Draw the relationship between effective stress and void ratio.

(2) When conducting a laboratory test on soil, we should consider ground conditions and situations during construction. Answer the following questions a), b) and c) regarding the following two cases (I) and (II) on/in ground consisting of a normally consolidated soil, as illustrated in Fig. 2.2.

(I) Point A beneath the foundation subjected to a load

(II) Point B in the backfill ground of underwater excavation

a) What kind of laboratory test is suitable for conservative (safe side) design considering lower strength for each of the constructions (I) and (II), respectively?

b) Explain the reasons for each of the suitable laboratory tests answered in the question a) in about 7 lines in English or 5 lines in Japanese, respectively.

c) Raise effective countermeasures or construction methods for each of the constructions (I) and (II), respectively.

Hydraulic condition: 水理境界条件, Saturated soil: 飽和土, Partially saturated soil: 不飽和土, Impermeable sheet: 不透水シート, One-dimensional consolidation: 一次元圧密, Total stress: 全応力, Pore water pressure: 間隙水圧, Unit weight: 単位体積重量, Effective stress: 有効応力, Void ratio: 間隙比, Compression index: 圧縮指数, Swelling index: 膨潤指数, Consolidation yield stress: 圧密降伏応力, Laboratory test: 室内試験, Conservative (safe side) design: 安全側の設計, Backfill ground: 背面地盤, Underwater excavation: 水中掘削, Failure plane: 破壊面（滑り面）, Sheet pile: 矢板

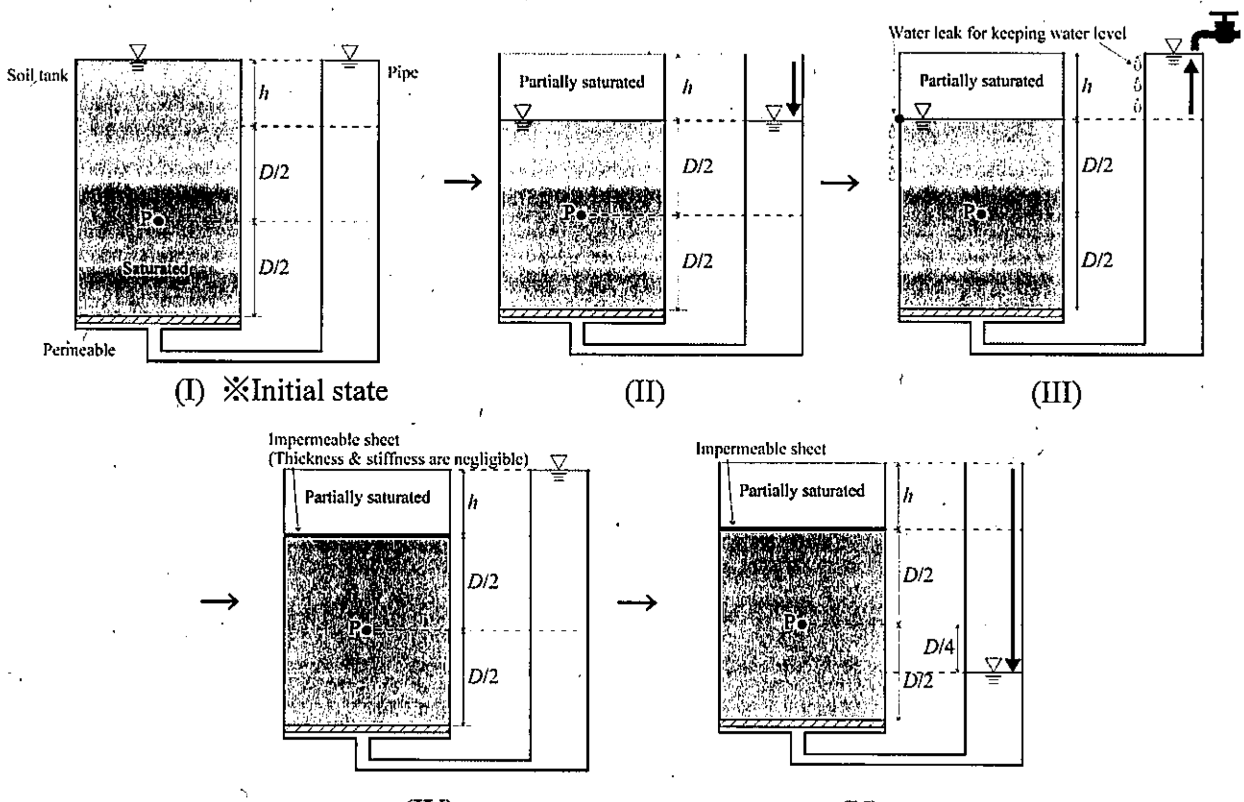


Figure 2.1: Hydraulic conditions of the tank

Table 2.1: Values for calculating the consolidation

γ_{sat}: the unit weight of saturated soil	20.0 kN/m^3	e_0: the initial void ratio	1.0	※Properties at the initial state (I)
γ_t: the wet unit weight of partially saturated soil	16.0 kN/m^3	p_{c0}: the initial consolidation yield stress	90.0 kPa	
C_c: the compression index	1.0	h	3.0 m	Specifications of the soil tank
C_s: the swelling index	0.2	D	10.0 m	
γ_w: the unit weight of water	10.0 kN/m^3			

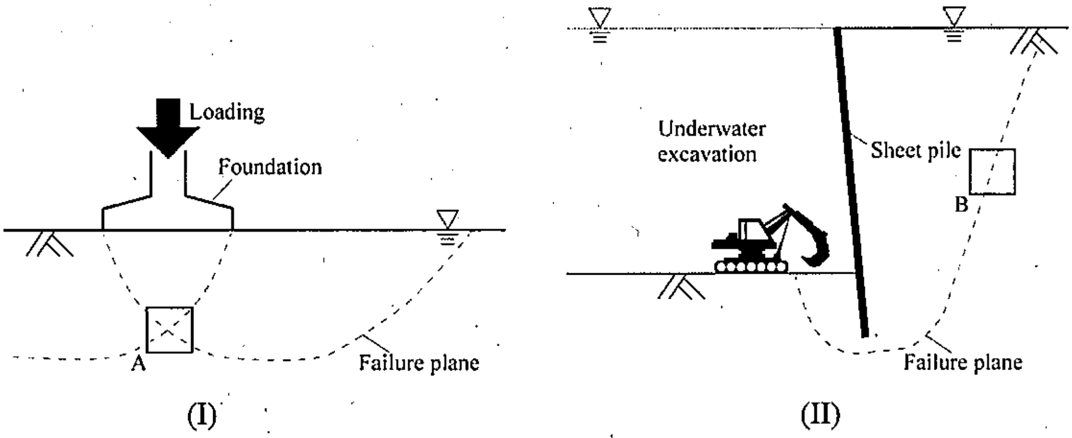


Figure 2.2: Cases (I) and (II) on/in ground consisting of a normally consolidated soil

分野 3/Field 3: (Hydrospheric engineering)

Question 1

Let us consider a 2-dimensional steady flow over a weir of height h_w as shown in Figure 1. The x-axis is horizontal and the z-axis is vertical in the figure. The flow is directed in the positive x-direction. The water depth is $h_1 + h_w$ at the upstream section (Section I), while it is h_2 at the downstream section (Section II). Answer the following questions.

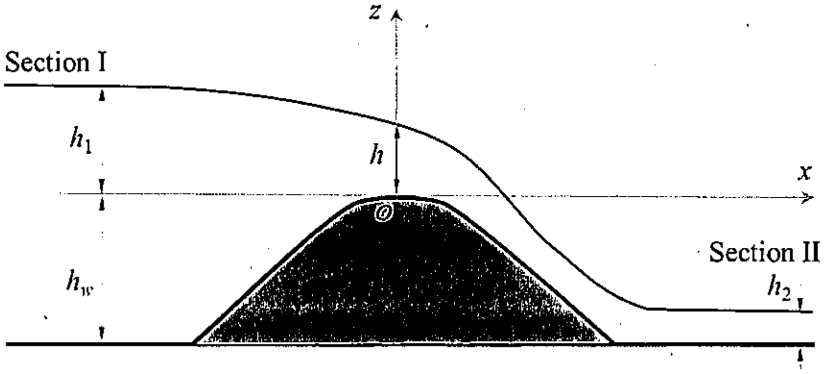


Figure 1: 2-dimensional steady flow over a weir.

(1) The flow discharge per unit width over the weir, q, is given by the following equation under certain assumptions:

$$q = h\sqrt{2g(h_0 - h)} \text{ with } h_0 = h_1 + \frac{V_1^2}{2g}, \qquad [1.1]$$

where g is gravitational acceleration, V_1 is the flow velocity at the Section I, h_0 is the upstream water head, and h is the flow depth on the weir crest as illustrated in Figure 1. Derive Equation [1.1] while clarifying the underlying assumptions.

(2) The flow transits from subcritical to supercritical flow while passing the weir crest. Therefore, <u>the flow state on the weir crest cannot be determined from either upstream or downstream conditions.</u> It is known that, in such situations, the flow depth at the transitional section can be given as follows:

$$h = \frac{2}{3}h_0, \qquad [1.2]$$

which leads Equation [1.1] to a well-known form of the overflow discharge formula:

$$q = \frac{2}{3}\sqrt{\frac{2}{3}gh_0^3}, \qquad [1.3]$$

a) Explain the above underlined sentence; why cannot it be determined?
b) Describe the theoretical basis of Equation [1.2].

(3) It is more convenient and practical to express the discharge formula in terms of the upstream water level h_1 which is directly measurable. Therefore, we often approximate Equation [1.3] as follows:

$$q = \frac{2}{3}\sqrt{\frac{2}{3}gh_1^3}, \tag{1.4}$$

a) Explain a condition of h_1 under which this approximation works well.
b) Estimate the percentage error in q associated with this approximation when $h_1 = h_w$.

(4) The accuracy of the discharge formula above is restricted by the assumptions on which Equation [1.1] is based. Therefore, in practice, we need to introduce the discharge coefficient, c_d, into Equation [1.4] as follows:

$$q = \frac{2}{3}c_d\sqrt{\frac{2}{3}gh_1^3}, \tag{1.5}$$

Laboratory tests have been conducted by many researchers to determine c_d for weirs of different geometries. One of the most restrictive assumptions is that the water pressure on the weir crest is hydrostatic.

a) Demonstrate that the pressure distribution on the weir crest generally differs from the hydrostatic one using Euler's equations of motion.
b) Discuss how the effect of the non-hydrostatic pressure on c_d varies with the weir shape.

(5) The design of a weir requires evaluating the horizontal forces generated by the flow.

a) Express the total horizontal force per unit width using ρ, g, h_w, h_1 and h_2 when $c_d = 1$, where ρ is density of water. You may neglect tangential forces on the weir surface.
b) Discuss the validity of the approximation of neglecting the tangential forces.

steady flow: 定常流れ, weir: 堰, crest: 天端, flow discharge: 流量, subcritical flow: 常流, supercritical flow: 射流, transitional: 遷移する, overflow discharge formula: 越流公式, hydrostatic: 静水状態の, non-hydrostatic: 非静水状態の, Euler's equations of motion：オイラーの運動方程式, tangential force：面に沿う方向の力

分野 3/Field 3: (Hydrospheric engineering)

Question 2

Read the following description about the velocity profile of an open channel flow and answer all the following questions. You may define variables and parameters if necessary. Show processes that led to your solution.

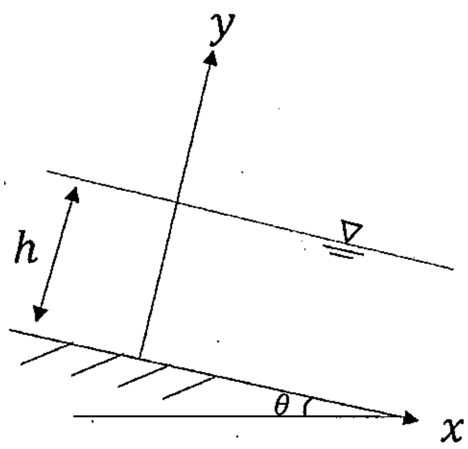


Figure 2: 2-dimensional open channel flow.

Let's discuss the velocity profile of a 2-dimensional steady and uniform open channel flow with the depth h and the gradient θ as a model of a river (see Figure 2). The 2-dimensional Navier-Stokes equation can be written as:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = gI - \frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right), \quad [2.1]$$

where u is velocity in x-direction, v is velocity in y-direction, g is gravitational acceleration, $I = \sin\theta$ is slope of the riverbed, ρ is density of water, P is pressure, μ is viscosity coefficient, x is axis along the river, y is the distance from the riverbed, and t is time.

Equation [2.1] includes the contribution of molecular viscosity stress (1). When Reynolds number is small and a laminar flow can be assumed, the velocity profile can be obtained by solving Equation [2.1] (2). However, to consider a realistic river flow, it is necessary to include the effect of turbulence. The variables in [2.1] are decomposed into ensemble means $(\bar{u}, \bar{v}, \bar{P})$ and fluctuations (u', v', P'):

$$u = \bar{u} + u', v = \bar{v} + v', P = \bar{P} + P'. \quad [2.2]$$

Then, the 2-dimensional Reynolds equation can be written as:

$$\frac{\partial \bar{u}}{\partial t} + \bar{u}\frac{\partial \bar{u}}{\partial x} + \bar{v}\frac{\partial \bar{u}}{\partial y} = gI - \frac{1}{\rho}\frac{\partial \bar{P}}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 \bar{u}}{\partial x^2} + \frac{\partial^2 \bar{u}}{\partial y^2}\right) - \left(\frac{\partial \overline{u'^2}}{\partial x} + \frac{\partial \overline{u'v'}}{\partial y}\right). \quad [2.3]$$

Equation [2.3] includes the contribution of turbulence. Although the ensemble means of the fluctuating components of velocity are zero (e.g., $\overline{u'} = 0$), the fluctuating components affect the mean flow velocity, $\bar{u}$ and $\bar{v}$. (3) In the model of a realistic river flow, the molecular viscosity term in [2.3] can be neglected except for the thin viscous sublayer. (4) In this case, Equation [2.3] can be solved for the steady and uniform flow by applying the mixing length model to parameterize Reynolds stress:

$$-\rho\overline{u'v'} = \rho l^2 \left|\frac{d\bar{u}}{dy}\right| \frac{d\bar{u}}{dy}, \quad l = \kappa y, \qquad [2.4]$$

where l is mixing length, κ is Karman coefficient.

The velocity profile obtained in this way can be empirically applied in all depths except for the viscous sublayer. This velocity profile can explain that the existing empirical equations of depth-averaged velocity such as the Chézy equation shown in [2.5] are reasonable approximation: (5)

$$U = C\sqrt{RI}, \qquad [2.5]$$

where U is depth-averaged velocity, C is Chézy coefficient, and R is hydraulic radius. The consideration of turbulence is extremely important to accurately estimate velocity profile and discharge.

Turbulence also plays an important role in sediment transport in river basins. (6) Furthermore, turbulence in boundary layers substantially affects global water cycles. (7) Thus, it is necessary to consider turbulent flows to estimate basin-scale water budgets. Therefore, modeling turbulence is extremely important for integrated water resources management.

(1) a) Which term in Equation [2.1] indicates the contribution of molecular viscosity stress?
b) In some fluids, molecular viscosity stress does not follow the answer of 1a). Discuss what characteristic of a fluid is necessary to formulate the contribution of molecular viscosity stress as the answer of 1a).
c) Provide an example of fluids whose contributions of molecular viscosity stress cannot be formulated as the answer of 1a).

(2) Solve Equation [2.1] for the steady and uniform flow and derive velocity profile $u(y)$. As boundary conditions, use non-slip condition at the bed ($y = 0$) and assume no molecular viscosity stress at the water surface ($y = h$).

(3) Using Equations [2.1] and [2.2], derive Equation [2.3]. Discuss why the fluctuating components of velocity affect the mean flow velocity, $\bar{u}$ and $\bar{v}$.

(4) Discuss what affects the existence and thickness of the viscous sublayer in a river.

(5) a) Solve Equation [2.3] for the steady and uniform flow and derive velocity profile $\bar{u}(y)$ by neglecting molecular viscosity stress and parameterizing Reynolds stress by Equation [2.4]. As the boundary condition, assume no Reynolds stress at the water surface ($y = h$). You may also assume $y \ll h$.

b) By deriving the depth-averaged velocity from your answer of 5a), discuss the relationship between your answer of 5a) and the Chézy equation [2.5].

(6) Discuss why turbulence in boundary layers is important for sediment transport in river basins. Answer in 1-2 lines.

(7) Discuss why turbulence in boundary layers is important for global water cycles. Answer in 3-5 lines.

velocity profile: 流速分布, steady and uniform open channel flow: 定常な開水路等流,
Navier-Stokes equation: ナビエストークス方程式, viscosity coefficient: 粘性係数,
riverbed: 河床, molecular viscosity stress: 分子粘性応力, Reynolds number: レイノルズ数,
laminar flow: 層流, turbulence: 乱流, ensemble means: アンサンブル平均,
fluctuations: 変動成分, Reynolds equation: レイノルズ方程式, viscous sublayer: 粘性底層,
mixing length model: 混合距離モデル, Reynolds stress: レイノルズ応力,
mixing length: 混合距離, Karman coefficient: カルマン定数,
depth-averaged velocity: 水深平均流速, Chézy equation: シェジーの式,
hydraulic radius: 径深, sediment transport: 堆積物輸送, boundary layers: 境界層,
water budgets: 水収支, non-slip condition: ノンスリップ条件

分野 4 / Field 4 (Transportation / Spatial information engineering):

Question 1

Answer the following questions.

(1) Draw a triangular fundamental diagram of traffic flow with traffic density k [veh/km] as the horizontal axis and traffic flow q [veh/h] as the vertical axis according to the following conditions:

- The wave speed in uncongested traffic is 60 [km/h].
- The wave speed in congested traffic is -20 [km/h].
- The maximum throughput is $2{,}400$ [veh/h].

(2) Consider an activity combination that maximizes the sum of utilities of the activities conducted during the time constraint. Find all the combination of activities maximizing the sum of utilities using a search tree and the branch-and-bound method, and show the calculation process. The utility and consumed time for each candidate activity are shown in Table 1.1. The total consumed time should not exceed 9 hours.

Table 1.1.: Candidate activities

	Activity	Utility	Consumed time [h]
A	Shopping for luxury	5	3
B	Shopping for daily use	3	2
C	Exercise	10	6
D	Meeting people	7	4
E	Watching a movie	8	5

(3) Suppose a major landslide severely damages the railroad network between the business district and the commuter suburb in a regional metropolitan area as shown in Fig. 1.1. There is no rail network to bypass the damaged section. To reach the business district, the residents in the commuter suburb must travel on the roads that have already been restored. Since road congestion would be severe if all commuters use their cars, the railroad operator and the local government cooperate to operate a free temporary bus service for railroad users. Obviously, the temporary bus service will help the residents who do not own cars.

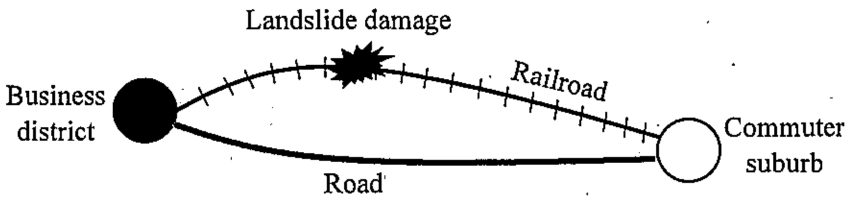


Figure 1.1.: Connection between the business district and the commuter suburb

a) Raise two measures that can be adopted to promote the use of temporary buses, and explain their strengths and weaknesses, in about 4 lines in English or 3 lines in Japanese for each measure.

b) Raise traffic management measures to reduce congestion other than the free temporary bus service, and explain their strengths and weaknesses, in about 4 lines in English or 3 lines in Japanese.

Traffic density: 交通密度, Traffic flow: 交通流率, Uncongested traffic: 非渋滞時, Congested traffic: 渋滞時, Maximum throughput: 最大スループット,
Time constraint: 時間制約, Combination of activities: 活動の組み合わせ, Search tree: 探索木, Branch-and-bound method: 分枝限定法, Utility: 効用, Time consumed: 消費時間,
Landslide: 土砂災害, Business district: 業務地, Commuter suburb: ベッドタウン, Regional metropolitan areas: 地方都市圏, Road congestion: 道路渋滞, Free temporary bus service: 無料の臨時バスサービス

分野 4 / Field 4 (Transportation / Spatial information engineering):

Question 2

(1) Answer the following questions about spatial information technologies.

a) Explain the principle of single point positioning GPS considering the contents of satellite messages and processing of receiver, each in about six lines in English or five lines in Japanese.

b) The web map tile technology becomes so popular due to smooth operability. Explain the most advantageous point of the map tile system for web map service providers in about six lines in English or five lines in Japanese.

(2) Consider the conversion of annual raw GPS data of millions of people to individual trip data for easier querying. Explain main steps involved and their processing algorithms in about 12 lines in English or 10 lines in Japanese in total.

(3) Recently emergence of deep learning enables us to have high accuracy of object recognition with training data. Draw the network diagram and calculate the number of parameters required for deep learning using a CNN (Convolutional Neural Network) to make a binary decision (for example, given image contains urban area or not) from three RGB channels when the input image is 512×512 pixels. The CNN settings shall be as follows.

a) Three convolutional layers

Filter size: 5×5

The number of filters: 64, 128 and 256 with three layers

Stride: one pixel

Padding type: zero padding

b) Three pooling layers

Filter size: 2×2

The number of filters: three layers after convolutional layers each

Type: max pooling

Stride: two pixels

Padding type: zero padding

c) Dense layer

Hidden layer of 256 neurons

Single point positioning: 単独測位, Satellite message: 衛星信号, Map tile technology: 地図タイル技術, Raw GPS data: 処理前の生の GPS データ, Convolutional Neural Networks: 畳込みニューラルネットワーク, Pooling layer: プーリング層, Dense layer: 圧縮層

分野 5/Field 5: (Urban / Landscape)

Question 1

(1) Fig. 1.1. shows a railroad plan of Tokyo at around 1900. The solid lines show existing railroads and the dashed lines show proposed railroads. Explain the backgrounds and (railroad operators' and government's) intentions of the railroad plan, within about 10 lines in English or 7 lines in Japanese.

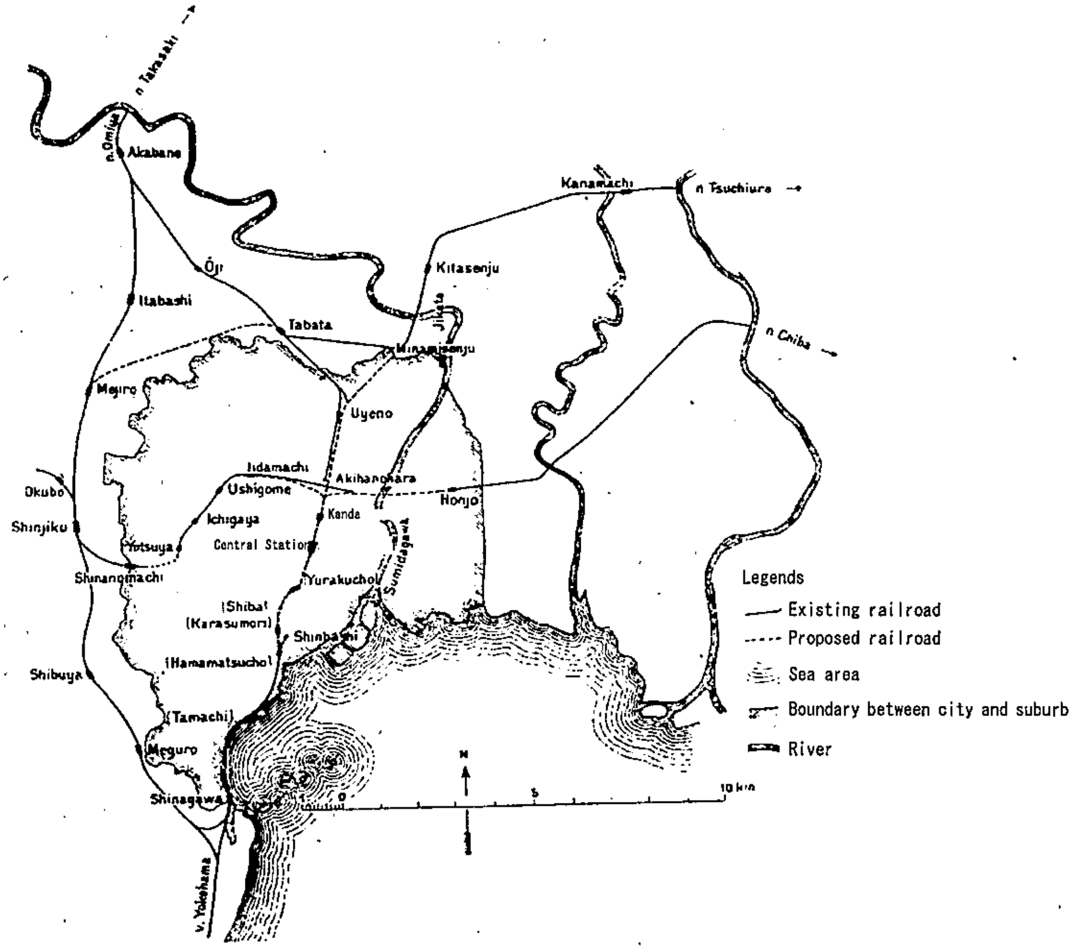


Figure 1.1.: Railroad plan in Tokyo (Partly revised)

(2) Tokyo Station has been the terminal and central station of the Tokyo metropolitan area since its opening in 1914. Discuss the future roles of Tokyo Station and its surrounding area, considering the possibilities of developing information and communication technology and opening the Maglev bullet train from Shinagawa station, in about 13 lines in English or 10 lines in Japanese.

Railroad plan: 鉄道計画図, Maglev bullet train: リニア新幹線,
Information and communication technology: 情報通信技術

分野 5/Field 5: (Urban / Landscape)

Question 2

Garrett Eckbo, a famous American landscape architect in the 20th century, gives his opinion on the quality of the landscape in the following extract from his work "The Landscape We See". Answer the following questions related to this text.

Quantitatively the landscape is total; it includes everything we see wherever we are. Qualitatively, however, is a different matter. We see? Who sees? Quality does not reside in the scene, nor does it reside in the observer. It resides precisely in the relationship which exists at a given time between the two. This is the design problem for all who are concerned with the quality of the landscape.

[…]

By *quality* I mean a relationship between an individual or a group of people and a landscape. This relationship involves human perception, comprehension, and reaction as a process which measures quality. The essence of landscape quality is neither in the landscape itself nor in people, but rather in the nature of the relationships which are established between them.

(G. Eckbo, *The Landscape We See*, 1969; partly revised)

A Japanese translation：

量として扱うなら、景観とは、どこであれその場所から見えるあらゆるものの総和である。しかし質を問うなら別の話になる。見える？だれが見るかによって見えるものはちがうのだ。質が宿るのはシーンのなかではないし、それを眺める観察者のなかでもない。正しくは、ある時点において両者のあいだに現出している関係のうちに、宿るのである。それこそが、景観の質に関心を寄せるすべての人にとっての、デザイン上の問題である。

［中略］

「質」という言葉でわたしが言いたいのは、ある個人もしくはある一群の人々と景観とのあいだの、関係のことである。この関係によって、景観の質を判定する一連の過程である、人間の認識、理解、反応が引き起こされるのである。景観の質の根源は、景観それ自体にあるのでも、人々にあるのでもない。むしろ、景観と人々とのあいだに築かれる関係に備わっている性質のなかにある。

(1) As G. Eckbo says, the quality of the landscape depends on the relationship between the scene and the observer, primarily the spatial relationship between visual targets and the viewpoint.

a) List two indicators for the spatial relationship between visual targets and the viewpoint and explain them briefly, within three lines in English or two lines in Japanese each.

b) Give an example of the landscape which is generated by intentionally creating spatial relationship between visual targets and the viewpoint, within eight lines in English or five lines in Japanese. You may use visual aids such as diagrams or sketches, if necessary.

(2) From G. Eckbo's point of view, we can say that "good" landscape design is to produce some qualities which bring us better human perception, comprehension, and reaction by creating or improving relationships between people and landscape. Give an example of what you think "good" landscape design in this sense and describe it, within fifteen lines in English or ten lines in Japanese. You may use visual aids such as diagrams or sketches, if necessary.

indicators for the spatial relationship between visual targets and the viewpoint：視対象と視点の空間的関係を表す指標

the landscape which is generated by intentionally creating spatial relationship：空間的関係を意図して創出することにより生み出された景観

分野 6/Field 6: (International Project / Management)

Question 1

Construction projects typically involve a wide range of risks, such as unforeseen site conditions, natural disasters and market price inflation. A contract is often considered as a tool for risk management, allocating each risk factor to one or more project parties.

Answer all the following questions. All answers should fit within a maximum of 2 pages.

(1) Discuss issues concerning the standard 'lump sum' construction contracts from the viewpoint of risk management.

(2) Choose one project risk factor, and discuss what contractual arrangements can effectively address the risk factor chosen. You may refer not only to the construction stage, but also to other related project stages, including design, pre-construction and post-construction.

Unforeseen site conditions: 予期しない現場条件

Market price inflation: 市場価格高騰

Project party: 事業関係主体

'Lump sum' contract: 総価請負契約

Contractual arrangements: 契約上の取り決め

分野 6/Field 6: International Project / Management

Question 2

Read the following text and answer the four questions below.

"Despite the global poverty rate having been halved since 2000, almost one billion people are still living without access to reliable and affordable electricity. A lack of access to modern energy impacts health and welfare and impedes sustainable development.(A) Knowing the location of those one billion is crucial if aid and infrastructure are to reach them. Traditionally, wealth and poverty have been measured through surveys of household income and consumption. However, many developing countries, particularly in sub-Saharan Africa, have only rudimentary economic statistics, and in many cases, lack regional data.(B) The international donor community is attempting to address poverty by spending billions of dollars annually in aid for the world's poorest countries based on the assumption that aid is flowing to where poor people live.

(...)

Given the paucity of relevant information, one of the most promising methods for estimating economic activity—especially for countries with low-quality statistical systems—is that of satellite-derived radiance.(C)"

(1) Regarding the underlined part (A), how does the access to modern energy impact poverty? Explain the mechanism within four lines in English or three lines in Japanese.

(2) Regarding the underlined part (B), why do many developing countries suffer from poor availability of regional data? Raise three reasons and describe them within three lines in English or two lines in Japanese for each.

(3) Regarding the underlined part (C), why is the satellite-derived radiance a promising method for estimating economic activity from a viewpoint of the international donor community? Raise three reasons and describe them within three lines in English or two lines in Japanese for each.

(4) As stated in the above text, the satellite-derived radiance has been often used for analyzing regional economic activities. Suppose that you would use the global satellite nighttime light data for post-evaluation of the impacts of a seaport investment on regional economies. Explain an appropriate method for this post-evaluation within eight lines in English or six lines in Japanese.

affordable： 購入しやすい, impede： 妨げる, rudimentary: 初歩的な,
paucity：不足, satellite-derived： 人工衛星由来の, radiance：輝き,
post-evaluation：事後評価, nighttime light：夜間光