Question Booklet of "Civil Engineering"

The 2020 Entrance Examination

Master's program

Department of Civil Engineering

Graduate School of Engineering

The University of Tokyo

August 26th, 2019 (Monday) 13:00 – 16:00 (180 minutes)

(Field 6 is not provided in English.)

Notice

- Please confirm you have your own "field selection survey form". Answer the questions in the two fields which you have selected. **If you answer questions in fields different from your selection, your answers will not be scored.**
- Please use one answer sheet for each **Question**.
- Please fill your examinee's number, field number, and question number for all the answer sheets (even they are blank).
- You can use both sides of the answer sheets. Additional answer sheet is not provided.
- For Field 7 (Mathematics), please select two questions out of the six questions. Please note that special answer sheets are provided for Field 7. Additional answer sheet is not provided.
- You have to return this booklet, field selection survey form, and all answer sheets after the examination.

Question Booklet of “Civil Engineering”

The 2020 Entrance Examination
Doctoral program
Department of Civil Engineering
Graduate School of Engineering
The University of Tokyo

August 26th, 2019 (Monday) 13:00 – 14:30 (90 minutes)

(Field 6 is not provided in English.)

Notice

- ○ Please confirm you have your own “admission survey form”. Answer the questions in the field which you have selected. **<u>If you answer questions in fields different from your selection, your answers will not be scored.</u>**
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Field 1 (Structures / Design)

Question 1

Consider a composite beam made by gluing two beams, each with height h and width w, with a rigid adhesive (see Figure 1). The Young's modulus of the upper and lower halves of the composite beam are E_1 and E_2, respectively ($E_1 < E_2$). Answer the following questions, assuming the Euler-Bernoulli beam theory is valid for this composite beam.

(1) Write the main assumption of Euler-Bernoulli beam theory.

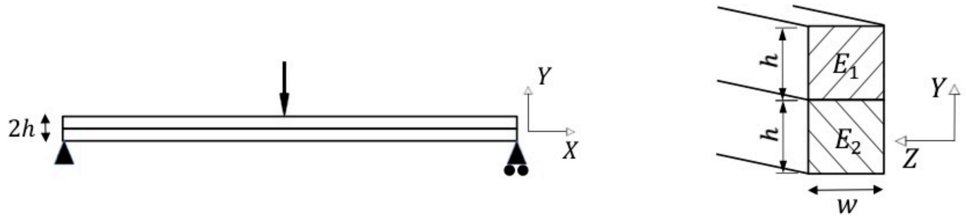
(2) Consider the deformation of the composite beam segment of infinitesimal length dx shown in Figure 2. Derive an expression for the axial strain of a line located an arbitrary distance y from the neutral axis, when the ends are subjected to a moment M. Assume that the neutral axis is located $\bar{y}$ distance below the bi-material interface, and the radius of curvature of the neutral axis of the deformed beam segment is R.

(3) Draw a sketch of the stress distribution due to the above axial strain.

(4) Considering the equilibrium in the X direction, derive an expression for $\bar{y}$ in terms of E_1, E_2 and h.

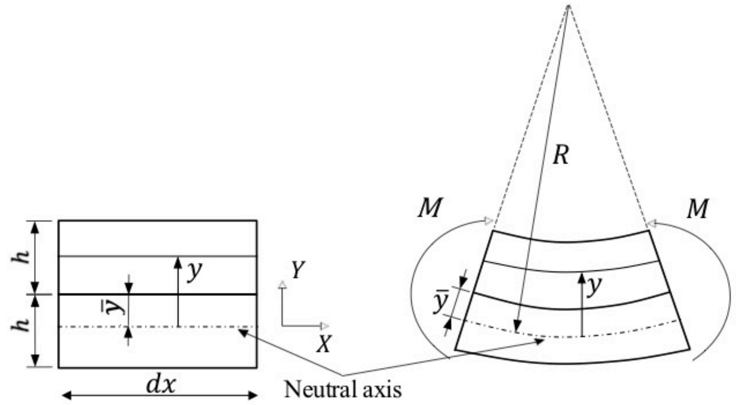
(5) Considering the moment equilibrium about the Z axis, derive an expression for the moment M in terms of E_1, E_2, $\bar{y}$, R, w and h. Simplify your answer assuming $E_2 = 3E_1$.

(6) Consider the simply supported composite beam shown in Figure 1, with $E_2 = 3E_1$. If a crack propagates along the interfaces of the two materials, show that the bending deformation after the crack is larger than that before the crack. Assume that the crack surfaces are frictionless and remain in contact. Also assume that the radius of curvature at the top and bottom faces of the cracked beam are nearly equal. It is not necessary to calculate the displacements due to the external load.



(a) A composite beam　　(b) Cross section

Figure 1 A bi-material composite beam and its cross section



(a) Undeformed shape (b) Deformed shape

Figure 2 Undeformed and deformed shapes of a beam segment of dx length

Question 2

Figure 1 shows a schematic diagram of a wave energy device, which consists of two identical cylindrical buoys (I and J) and a rigid connection bar. The buoys, with cross-sectional area A, mass m and height h, are attached to the bar through hinges. The buoys I and J are immersed in water, with the exposed heights to the water surface x_i and x_j respectively, and only move in the vertical direction. The length of the bar is l, and its mass is negligible. The middle hinge is located at the height d from the still water surface. During operation, waves cause the bar to rotate through an angle θ. Neglect torque and friction acting at each hinge, as well as viscous drag and kinetic energy of the water. The density of water is ρ and the gravitational acceleration is g. Assuming $0 < x_i < h$ and $0 < x_j < h$ in still water condition (no waves).

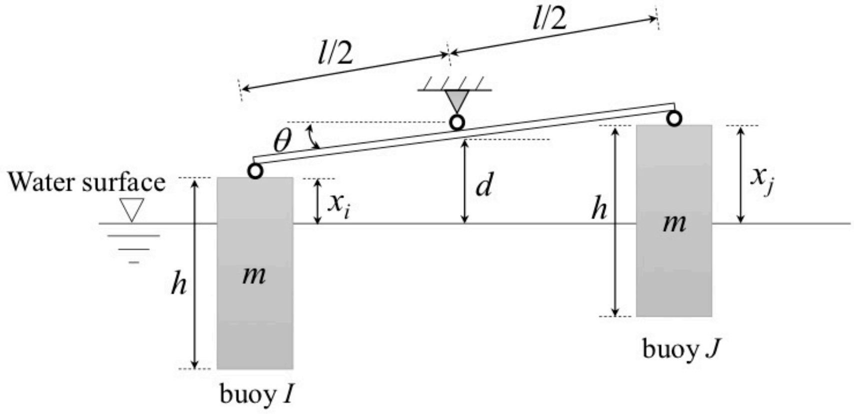


Figure 1

(1) When $d = h/2$, answer the following questions.
   a) Obtain an expression for the potential energy of buoy J.
   b) Obtain the equation of motion of the device.
   c) Linearize the equation of motion in b) for small θ and obtain the natural frequency.

(2) The energy generation efficiency depends on the natural frequency of the device. The value of d changes due to tides. Explain how the variation of d affects the efficiency of the device in about three lines.

Field 2 (Concrete engineering / Geotechnical engineering)

Question 1

Answer the following questions.

(1) When the amount of coarse aggregate in concrete changes between 0% (i.e. only mortar) and 100% (i.e. no mortar), illustrate how the compressive strength changes and explain the reason in about five lines.

(2) Give three reasons why aggregate is used in concrete and explain in about one line for each reason.

(3) The effect of concrete compressive strength on the ultimate capacity of reinforced concrete beam in flexural tension failure is smaller than that of the steel strength. Explain the reason in about five lines using the flexural capacity formula. Define the variables for the formula.

(4) Reinforcement congestion can happen at the beam-column joint in reinforced concrete structures. Explain the possible problems caused by the congestion in the design, construction, and maintenance stages in about three lines each.

(5) Answer whether each of the following statements regarding properties of concrete is correct or wrong. If a statement is wrong, explain the reason in about two lines.

a) The relationship between the water-cement ratio and the compressive strength of concrete depends on the types of cement even after a long time elapsed.
b) The relationship between the unit water content and the slump value of concrete does not depend on the particle size or shape of aggregate.
c) In general, the carbonation depth of a concrete structure that is not subjected to rainwater is lower than that of a concrete structure subjected to rainwater.

Question 2

(1) Answer the following questions. You may use illustrations if necessary.

a) Explain the mechanism of liquefaction in sandy ground during an earthquake, in about four lines.
b) Explain the mechanism of ground settlement caused by the decrease of ground water level due to excessive pumping, in about four lines. There are some cases where ground water level is intentionally lowered. Present two applications where such method is effective.

(2) Answer the following questions on shear tests of soil.
There are several testing methods to evaluate the strength and deformation characteristics of soil, such as (a) box shear test, (b) triaxial compression test and (c) hollow cylindrical torsional shear test. Explain each of these three testing methods with its advantage and disadvantage, in about four lines for each method.

(3) Answer the following questions on the active earth pressure and water pressure on the 10m tall retaining wall, as illustrated in Figure 1. The backfill soil has internal friction angle ϕ'=30º, cohesion c'=5.0 kN/m^2, void ratio e=0.70, and soil particle density ρ_s=2.7 g/cm^3 (irrespective of degree of saturation). The back surface of the wall is vertical and smooth. Density of water ρ_w=1.0 g/cm^3 and gravitational acceleration 9.8 m/sec^2. If needed, set $\sqrt{3}$=1.7.

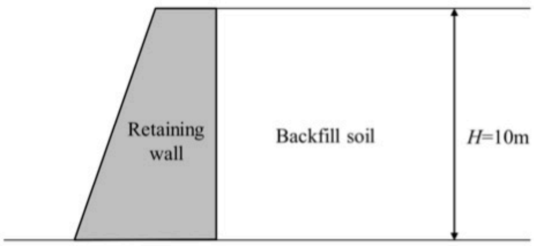


Figure 1

a) Based on Rankine's earth pressure theory, calculate the coefficient of active earth pressure of the backfill soil.
b) Calculate the wet unit weight γ_t of backfill soil when the degree of saturation S_r = 50%, and the saturated unit weight γ_{sat} when S_r =100%, respectively.
c) Calculate the active earth pressure on the wall at 5 m height when the water level is below the bottom of the wall and the degree of saturation of the backfill soil S_r = 50%.
d) Calculate the horizontal pressure (in total stress) on the wall at 5 m height when the water level reaches the top surface of the backfill soil due to heavy rainfall. The degree of saturation of the backfill soil S_r = 100%.
e) Present countermeasure(s) in order to avoid the water pressure on retaining walls during heavy rainfall, in about three lines.

Field 3 (Hydrospheric engineering)

Question 1

Answer the following questions. The gravitational acceleration is g.

(1) Consider the water flow at constant rate Q in the frictionless open channel shown in Figure 1. The flow sectional area A of this channel is given by

$$A = ah^{\frac{3}{2}}$$

where, a is a constant and h is the water depth at the channel center.

a) Express the specific energy E as a function of h.
b) Derive the critical water depth h_c as a function of the variables such as Q and a.
c) If h is the critical water depth h_c, derive the specific energy E_c as a function of h_c.

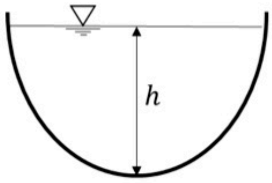


Figure 1

(2) Water is flowing in the open channel with a triangular cross section, which is symmetrical as shown in Figure 2. The walls have friction, and cross-sectional slope of the channel is $1/m$. Assuming that the flow sectional area A is constant, derive m which maximizes the flow rate. Here, h is the water depth at the channel center.

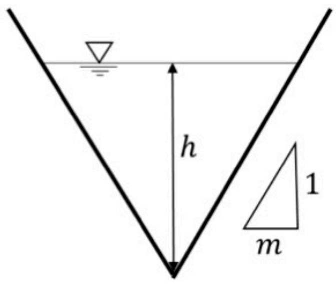


Figure 2

(3) Water flows in the open channel which has a mound of top height z_0 on its bed, as shown in Figure 3. The friction of the channel is negligible, and the unit width flow rate is q. Here, h is the water depth with $h = h_0$ in the upstream section of the mound. The horizontal axis along the riverbed is x, and the water level in the section with the mound $H = h + z$.

a) Derive $\frac{\partial H}{\partial x}$ in the section with the mound as the function of Froude number $F_r = \sqrt{\frac{q^2}{gh^3}}$ and $\frac{\partial z}{\partial x}$.

b) If the flow is subcritical in all sections, explain the reason why the water level drops in the section with the mound within five lines.

c) Derive an expression for z_0 when the water depth at the mound top is the critical water depth h_c.

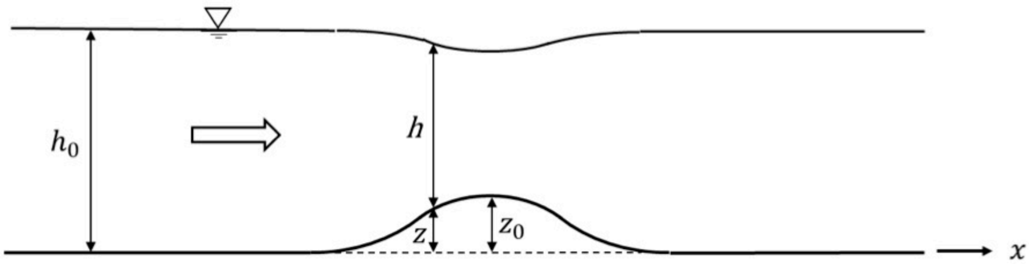


Figure 3

(4) Water flows at a constant flow rate Q in a rectangular cross-section channel with horizontal bed whose width abruptly changes from B_1 to B_2, as shown in Figure 4. Assume that channel friction is negligible. The depth of section 1 is h_1, the depth of section 2 is h_2, the fluid density is ρ, the cross-sectional average velocity of section 1 is v_1, and the cross-sectional average velocity of section 2 is v_2. The water depth in front of the Wall-e and the Wall-f is h_1, and the water pressure at this location can be regarded as hydrostatic. Answer the following questions.

a) Show the equation of momentum conservation law between cross section 1 and cross section 2 using v_1, v_2, h_1, h_2, B_1 and B_2.

b) When $A = \frac{h_2}{h_1}$ and $C = \frac{B_2}{B_1}$, derive the upstream Froude number $F_{r1} = \frac{v_1}{\sqrt{gh_1}}$ as a function of A and C.

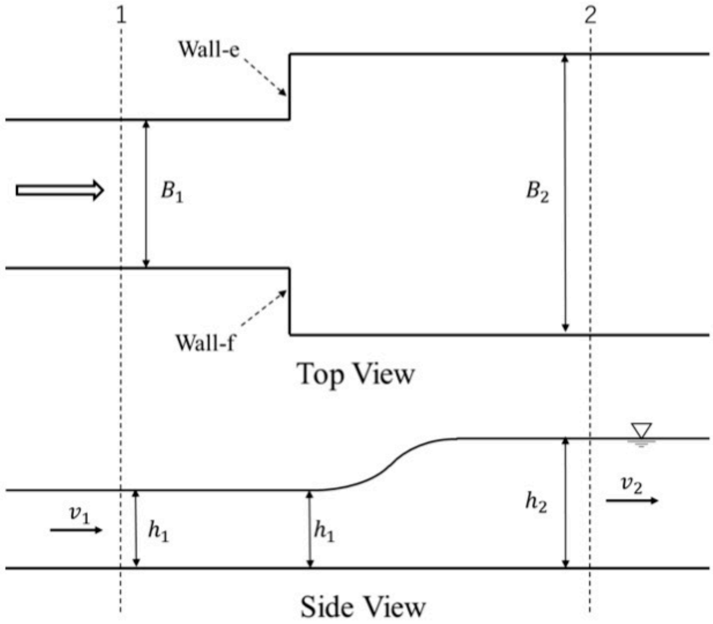


Figure 4

Question 2

Let us consider two-dimensional flow fields, either on a x-y horizontal plane or on a x-z vertical plane, determined by a set of velocity potential and stream function. Answer the following questions.

(1) Let us first focus on three different flow fields on a x-y horizontal plane, determined by three different sets of velocity potential and stream function expressed in equations [1], [2] and [3], respectively.

$$\phi_1 = Vx, \quad \psi_1 = Vy \tag{1}$$

$$\phi_2 = \frac{Q}{2\pi}\log r, \quad \psi_2 = \frac{Q}{2\pi}\theta \tag{2}$$

$$\phi_3 = \phi_1 + \phi_2, \quad \psi_3 = \psi_1 + \psi_2 \tag{3}$$

Here, $r = \sqrt{x^2 + y^2}$ and $\theta = \arctan(y/x)$ are circular coordinates on x-y horizontal plane and V and Q are positive constants.

a) Show that these flow fields satisfy the mass conservation equation of incompressible flow and the condition of irrotational flow.

b) Express dimensions of V and Q by using the dimension of horizontal length L and the dimension of time T. Describe physical meanings of V and Q.

c) Using streamlines, illustrate the flow field determined by ψ_1 and ψ_2, respectively.

d) Express the horizontal flow velocity components in x and y directions, (u_1, v_1), (u_2, v_2) and (u_3, v_3), at arbitrary horizontal locations determined by velocity potentials, ϕ_1, ϕ_2 and ϕ_3, respectively.

e) Show the Bernoulli Equation of the steady flow field on a two-dimensional horizontal plane.

f) Let us introduce the pressure difference, $\Delta p = p_B - p_A$, with p_A and p_B, pressures at point A, (x, y)=(0, 1) and point B, (x, y)=(2, 0), respectively. Express this pressure difference, Δp_1, Δp_2, and Δp_3 under the flow fields determined by velocity potential ϕ_1, ϕ_2 and ϕ_3, respectively. Let ρ be a density of the fluid.

g) Compare the relationship among these three pressure differences, determined in f) with the relationship among (u_1, v_1), (u_2, v_2) and (u_3, v_3), determined in d). Briefly explain in around four lines how these two relationships are different from each other and why they are different.

(2) Based on the small amplitude wave theory on x-z vertical plane, the velocity potential ϕ and water level fluctuations η around a still water level of a regular progressive wave are determined by the following equations.

$$\phi = \frac{ga}{\omega}\frac{\cosh k(z+h)}{\cosh kh}\sin(kx-\omega t) \qquad [4]$$

$$\eta = a\cos(kx-\omega t) \qquad [5]$$

Here g is gravity acceleration, a is amplitude of the water level fluctuations, ω=2π/T is angular frequency, T is wave period, h is still water depth, k=2π/L is wave number, L is wave length, t is time, x is horizontal axis positive in the wave propagating direction and z is upward vertical axis with $z = 0$ at still water level. Density of the fluid is determined as ρ. Answer the following questions.

a) Express the velocity components (u,w) in the horizontal and vertical directions, respectively.
b) Using variables such as velocity potential ϕ velocity components (u,w) and pressure p, express the Bernoulli Equation of the unsteady flow field on a two-dimensional vertical plane.
c) Based on the assumption of the small amplitude wave theory, the square terms of velocity components (u,w) are sufficiently small and thus can be neglected and the velocity potential at the water surface $z = \eta$ can be approximated by equation [4] with $z = 0$. Based on this assumption, determine the pressure at the bottom, i.e. at $z = -h$, using equations [4] and [5] and the Bernoulli Equation expressed in b). Here, the atmospheric pressure at the water surface is determined as p_0, which is assumed to be constant both in time and in x direction.
d) Express the hydrostatic pressure at the bottom for the total depth $h+\eta$ when water level is given by η in equation [5]. Explain in around two lines how this hydrostatic pressure differs from the one obtained in c) and discuss in around three lines what you should consider if you were to measure the water level fluctuations by using a pressure sensor installed on the bottom.

Field 4 (Transportation / Spatial information engineering)

Question 1

(1) Answer the following questions about the capacity related to transportation facilities.

a) Describe the two standard definitions of capacities related to transportation facilities within five lines.

b) Describe the specific examples of the above defined capacities related to stations and airport, respectively, within five lines.

(2) Answer the following questions about equilibrium.

a) Explain the stability of the equilibrium in the Wardrop first principle within five lines.

b) Assume that a share of road traffic and public transport has reached an equilibrium. Explain the change in equilibrium point due to road traffic improvements within five lines.

(3) Consider problems of public transport service in rural area.

Based on the game theory, assume both users and operators of public transport service try to maximize their gains. Explain a collaborative measure between them from this viewpoint in order to vitalize public transport service in rural area within five lines.

Question 2

Answer the following questions.

(1) Answer the following questions about recent positioning technologies.

a) Explain the principle of D-GPS (Differential GPS) in about three lines.

b) Explain the background of GPS Selective Availability (S/A) in 2000 by Presidential directive in the United States in about three lines.

c) Explain the mechanism of A-GPS (Assisted GPS) in mobile phone that started in early 2000's in about three lines.

d) Explain the mechanism of Quasi-Zenith Satellite System already operated in Japan in about three lines.

(2) Answer the following questions about the data structure of spatial information.

a) Find and show the minimum cost route and its cost from node 0 to node 9 of the following road network structure displayed in Figure 1. In addition, explain the calculation procedure for finding the minimum cost route using Dijkstra Algorithm in about seven lines using information in Figure 1.

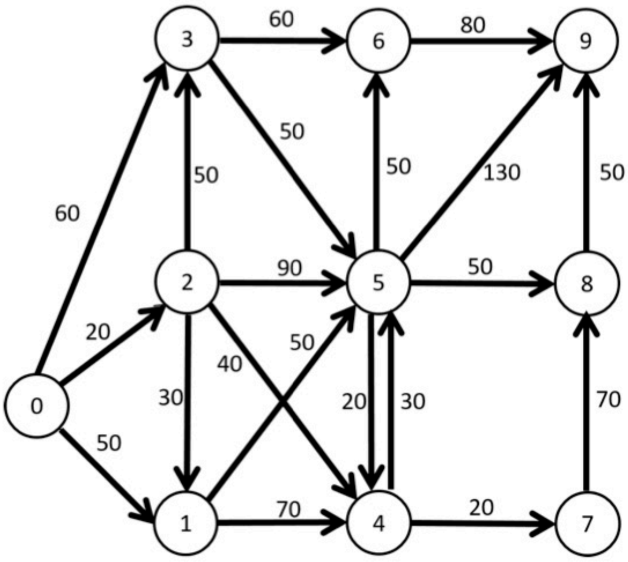


Figure 1. Target road network

(Number in circle shows node number and number on link shows cost of the link between nodes.)

b) OpenStreetMap, that sometimes called as "Wikipedia for maps", has been started in 2004 and used for various commercial services. Explain two important potential concerns of using OpenStreetMap when used for applications such as least-cost route-finding problem in about five lines in total.

(3) Read the following sentences on spatial information and answer correct combination regarding true/false from A to E with underlined phrases.

Spatial informatics has put its pivotal foot in practical research such as GIS software originated from computational geometry (①) and the GPS technology used for the car navigation system since 1990's (②). Recently it has developed to an independent field of science that systematically deals with information of the real world such as nation-wide or urban areas.

In the year 2000's, while internet-based commercial services such as Google Maps had launched, international standardization of GIS gave rise to the number of open source software such as QGIS (③). As the above-mentioned services and software have been commonly used, importance and value of detailed data in individual field had been recognized. Especially, with the recent rise of Artificial Intelligence technologies such as machine learning, these data play an important role as training data.

It is required to clarify the data ownership, and the right of data processing, protection, and transfer (including cross-border transfer). Open data policy should be positively applied to the data related to public activities of national/local governments excluding confidential information. The quality of data exchanging environment should be well maintained, while it is occasionally found that some commercial companies (④) exclusively keep large-scale data including personal information. Recently, Japanese government has improved the personal information protection law (⑤). As troubles related with spatial information has been increasing such as spoofing of location information, these efforts on the ownership and rights of data are essential for safe and comfortable life of citizens.

(A) ①True ②True ③True ④True ⑤True

(B) ①True ②False ③False ④False ⑤False

(C) ①False ②True ③True ④True ⑤True

(D) ①True ②False ③False ④False ⑤True

(E) ①True ②False ③True ④True ⑤ True

Field 5 (Urban / Landscape)

Question 1

Consider small- and medium-sized coastal cities which can be affected by Nankai megathrust earthquake (assumed magnitude is 9). Discuss your ideas about urban planning which should be implemented in advance (=prior reconstruction) for these cities in about 30 lines.

Question 2

The following text written by Christopher Alexander (1936-), an American scholar of architecture, gives his opinion on how the public spaces for local communities should be. Answer the questions (1) - (4) related to the underlined parts.

To create the concentrations of people in a community, facilities must be grouped densely round very small public squares which can function as nodes – with (1) all pedestrian movement in the community organized to pass through these nodes. … the facilities grouped around any one node must be chosen for their symbiotic relationships. It is not enough merely to group communal functions in so-called community centers. For example, church, cinema, kindergarten, and police station are all community facilities, but they do not support one another mutually. Different people go to them, at different times, with different things in mind. There is no point in grouping them together. To create intensity of action, (2) the facilities which are placed together round any one node must function in a cooperative manner, and must attract the same kinds of people, at the same times of day. …

It is natural that every public street will swell out at those important nodes where there is the most activity. And it is only these widened, swollen, public squares which can accommodate the public gatherings, small crowds, festivities, bonfires, carnivals, speeches, dancing, shouting, mourning, which must have their place in the life of the town. But for some reason there is a temptation to make these public squares too large. Time and again in modern cities, architects and planners build plazas that are too large. They look good on drawings; but in real life they end up desolate and (3) dead. Our observations suggest strongly that open places intended as public squares should be very small. As a general rule, (4) we have found that they work best when they have a diameter of about 60 feet (18m) – at this diameter people often go to them, they become favorite places, and people feel comfortable there. When the diameter gets above 70 feet (21m), the squares begin to seem deserted and unpleasant.

(C. Alexander et al., *A PATTERN LANGUAGE*, 1977; partly revised)

(1) What is the effect of these nodes on the legibility of a city? Explain it based on Kevin Lynch's theory on the image of the city, within five lines.

(2) Give a hypothetical example of "the facilities which are placed together round a node and function in a cooperative manner" and explain it, within eight lines.

(3) What are the requirements in spatial design for public squares, besides the size of them, in order that they do not end up "dead" as the place for local community? Write one requirement that you think the most important and explain the reason within ten lines.

(4) Why do the squares for local communities work best when they have a diameter of about 60 feet (18m)? Discuss the reason(s) based on the idea of human scale, within eight lines.