Montogue

QUIZ GT301
Embankment Dams and Dam Engineering

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▸ PROBLEMS

PROBLEM 1

True or false? Consider the following statements, regarding the theory of embankment dams and dam engineering in general.

1.( ) In earth embankment construction works, the best soil is always reserved for the core and cutoff, and must be well-compacted. Basically, the higher the clay percentage, the more compaction and care in construction is required. The upstream region does not require highly impermeable clays, as these would lead to undesirable uplift pressures developing beneath this section of the embankment.

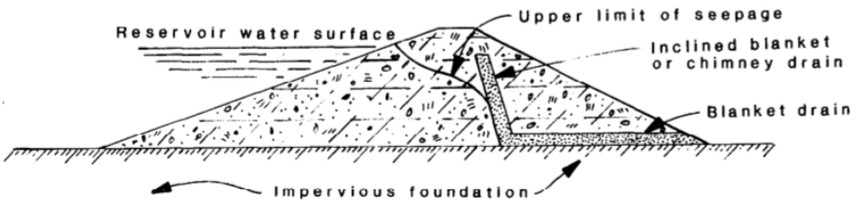
2.( ) For some dams constructed with impervious soils having flat embankment slopes and infrequent high reservoir levels, the phreatic surface may be contained well within the downstream slope and escape gradients may be sufficiently low to prevent piping failure. For these conditions, when it can be ensured that the variability in the characteristics of borrow materials will not result in adverse stratification in the embankment, no vertical or horizontal drains are required to control seepage through the embankment.

3.( ) Downstream slopes of homogeneous dams or dams with outer sand and gravel zones should be protected against erosion caused by wind and rainfall runoff. This can be accomplished by addition of a layer of rock, cobbles, or sod. If the downstream zone of an embankment consists of rock or cobble fill, no special treatment of the slope is necessary.

4.( ) Rockfill is required to be hard and durable. The means of measuring this are seldom specified and in many dams such a requirement will not be obtainable at all. For instance, it is hard to achieve these conditions when siltstone or other slake-susceptible rocks are being used, as these may break down on repeated exposure to wetting and drying. Nevertheless, such breakdown only occurs on the surface of the fill and is not detrimental to the shear strength or compressibility of the rockfill as a whole, provided it is well compacted and watered during compaction.

5.( ) In the specification of earthfill for embankment projects, it is normal to specify the roller type and weight. For earthfill it is common to require a rubber-tired roller because, among other reasons, the rubber-tire compression action breaks up pieces of cemented soil or weathered rock in the fill.

6.( ) Recently, to avoid construction defects such as loose lifts, desiccation, and dispersive soils, the use of inclined filter drains with a horizontal drainage blanket has become almost standard. The following figure illustrates the control of seepage with an inclined chimney drain and a horizontal drainage blanket. Another method of providing drainage has been the installation of pipe drains. In small dams, pipe drains can be used as substitutes of a horizontal drainage blanket or pervious zones.



7.( ) The primary cause of failure of embankment dams in the United States is overtopping as a result of inadequate spillway capacity. The next most frequent cause is seepage and piping. Seepage through the foundation and abutments is a greater problem than seepage through the dam.

8.( ) Spillway erosion and the inability to carry flood flows are the main reasons behind many earth dam failures. Once erosion on a grassed spillway or a friable rock spillway has started, it is very difficult to prevent it from recurring without continual maintenance and remedial procedures. Normally this signifies that solid rock should have been used for spilling flood water in the first place.

9.( ) Most energy released as ground motion during earthquakes is transmitted in the sub-10 Hz frequency band, so that an elastic structure with natural frequency within that range is potentially at risk. For large embankments, it can be calculated that their natural frequency is of the order of f_n = 1 Hz and below, thus registering in a frequency band that is not particularly vulnerable to most earthquakes' energy release.

10.( ) The upgrading and rehabilitation of older embankment dams is assuming great importance within the older industrialized nations where, insofar as dams are concerned, much of the national infrastructure was constructed in the 19th and 20th centuries. One example of defect that may require a remedy is the existence of inadequate parameters controlling the stability of slopes. Inadequate stability of the downstream slope, either involving an excessively steep slope or a high phreatic surface, can be easily counterbalanced by construction of a downstream berm of free-draining fill.

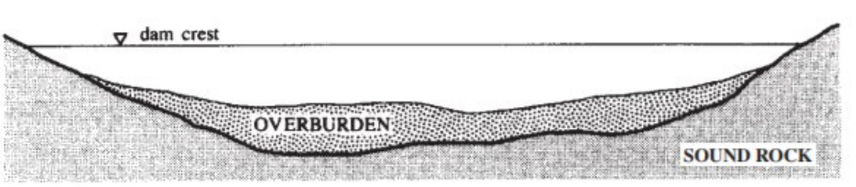
PROBLEM 2

According to the ICOLD, a dam is considered large when it is more than 15 meters in height (measured from the lowest point in the general foundation to the crest of the dam), or, in the case of dams having a height between 10 and 15 meters, if it obeys at least one in four specific criteria. Which of the following is **not** one such criterion?

A) The crest length should not be less than 500 meters.
B) The capacity of the reservoir formed by the dam is not less than 10^6 m^3.
C) The maximum flood discharge is not less than 1000 m^3 per second.
D) The dam is of unusual design or had particularly difficult foundation problems.

PROBLEM 3

A wide valley with deep overburden of fine-grained soil, as illustrated below, is particularly suitable for a



A) Earthfill embankment dam.

B) Rockfill embankment dam.

C) Buttress concrete dam.

D) Arch or cupola concrete dam.

PROBLEM 4

The strength, permeability, and compressibility of the dam foundation have a major influence on the embankment type. Regarding dam foundations, which of the following is **false**?

A) A strong, low-permeability rock foundation is the best choice of foundation for most dam types, favoring, for example, the construction of concrete-based structures such as a concrete face, a concrete gravity, or a concrete arch dam.

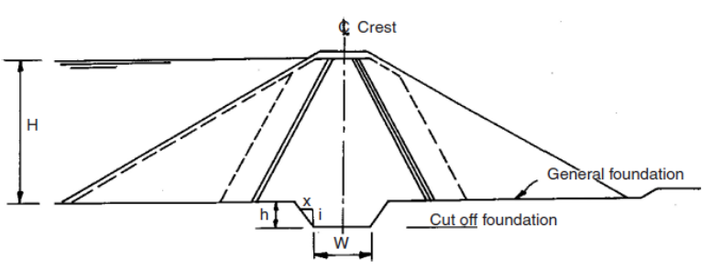
B) In earthquake zone areas, the presence of loose to medium dense saturated sandy soils in the foundation is an important aspect to consider during dam design. Such conditions may necessitate removal or densification of the sandy soil and use of weighting berms.

C) Dams on karst limestone foundations are a special case as they, unlike highly weathered metamorphic and most sedimentary rocks, provide a firm base against leakage and allow the engineer to do away with the need for extensive grouting.

D) In some sedimentary rocks that have been subjected to folding or faulting, particularly interbedded claystone/mudstone and strong sandstone, there is a high likelihood of the existence of bedding plane shears. This results in low effective friction angles and restricts the choices of possible embankments to flat earth and rockfill slopes, usually equipped with vertical and horizontal drains.

PROBLEM 5

Regarding the preparation of foundations for embankment dams, which of the following is **false**?



A) Deployment of horizontal filter drains is only needed if the foundation is soil or erodible rock.

B) If a filter is placed, the surface should be rolled prior to placement of the filter to provide a homogeneous structure for control of seepage.

C) The ratio of cutoff width, W, to the height of the dam, H, depends on a number of factors. For excavations in rock, this ratio depends on the quality of the rock and is lower for low permeability, non-erodible rock or higher for more permeable, friable materials.

D) For cutoffs in rock, if the exposed rock is susceptible to slaking by wetting and drying, it should be covered with a cement-sand grout or concrete. Generally, this should be done as soon as the foundation is exposed, but may also be executed after a second cleanup, right before placement of the earthfill core.

PROBLEM 6

According to the US Bureau of Reclamation's 1987 survey of approximately 100 dams (see USBR, 1987, Section 6.22), the best material for protection of the upstream face of an embankment dam was found to be

A) Dumped riprap.

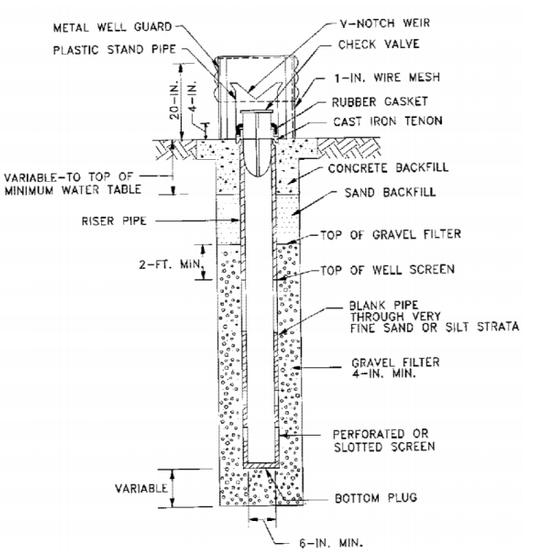
B) Hand-placed riprap.

C) Concrete blocks.

D) Concrete pavement.

PROBLEM 7

The figure below illustrates the elements of a typical pressure relief well. Regarding these structures, which of the following statements is **false**?



A) The presence of relief wells in a dam or levee tends to increase the total quantity of seepage beneath the structure.

B) The effective well radius to be used in design computations is calculated as the outside radius of the well screen plus one-half the thickness of the filter.

C) The backfill indicated as sand in the figure above normally consists of concrete sand or otherwise excess filter material. Its only function is to fill the annular space around the riser pipe to prevent collapse of the boring.

D) The filter should consist of natural material made up of hard durable particles, and should contain no detrimental quantities of organic matter or soft, friable, thin or elongated particles. One example of feasible material is crushed carbonate aggregates, which are resistant against break down and dissolution when subjected to acid treatment as part of future rehabilitation operations.

PROBLEM 8

Which of the following is not a defensive design measure used to protect dams from earthquake effects?

A) Making the impervious zone more plastic.

B) Increasing the freeboard.

C) Flattening the embankment slopes.

D) Narrowing the dam crest.

PROBLEM 9

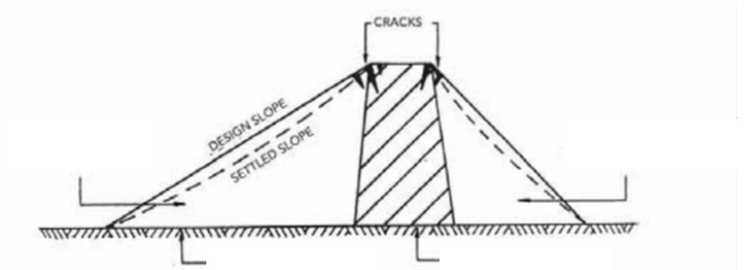
"_____ is the process by which finer soil particles are moved through constrictions between larger soil particles by seepage forces. Soils susceptible to _____ are usually described as internally unstable. Internally unstable soils are usually broadly graded soils with particles from silt or clay to gravel size, whose particle size distribution curves are concave upward, or gap-graded soils."

What is the term that correctly completes the blank spaces above?

A) Piping.
B) Suffusion.
C) Blowout.
D) Differential settlement.

PROBLEM 10

Cracks occurring on the crest edges of small earth embankments, as illustrated below, may be indicators of:



A) The fact that the freeboard provided to shield the structure against overtopping by waves was insufficient.
B) The fact that the protection against seepage in the soil has not proven sufficient to prevent the development of strong uplift pressures.
C) The fact that the core has been compacted comparatively more than other parts of the embankment.
D) The fact that the seismic activity in the area of the embankment is too intense to ensure mechanical safety for such steep slopes.

PROBLEM 11

Foster et al. report that, historically, about half of piping failures can be attributed to the presence of conduits or outlet pipes through earth dam embankments. The traditional approach to overcome this problem (though not necessarily the most effective) is:

A) Avoid placing the conduit across compressible soil zones or close to filters.
B) Using a greater number of small conduits rather than a single, erosion-susceptible large conduit. The additional conduits can be made of weaker materials, such as PVC.
C) Providing concrete cutoff collars around the conduit, lengthening the seepage path and shielding the conduit from penetration by stress-induced cracks.
D) Detailing conduit joints with greater care both in design and construction, as these components are usually the most common sites of erosion.

PROBLEM 12

Embankments constructed for tailings disposal or for storage lagoons differ from conventional embankment dams in a number of regards. Which of the following is **false**?

A) Tailings embankments, particularly the smaller ones, tend to be "minimum cost" structures. Design and construction standards, particularly on older projects, may consequently fall short of the standards for modern embankment practice, particularly when the structure is made of low quality fills.

B) The retained fines or slurry can be of very high density, as much as three or more times the density of water. Because of their inherently high density, tailings offer greater resistance to flow and, consequently, impoundments of these substances can be designed with smaller freeboards and limited overflow capacity.

C) A common construction practice is to raise the crest of the retaining embankment and retention level of the stored waste incrementally and in parallel, so that the embankment functions as a dam and is itself raised in stages. Another common practice is the use of hydraulic filing, in which natural silt or waste fines, if suitable, are fluidized and pumped to hydro-cyclones located at intervals along the planned embankment.

D) Due to a lack of discharge area, acid generation control, or other reasons, the tailings may have to be deposited under water. This is known as sub-aqueous deposition. Fine, high clay content tailings deposited sub-aqueously will usually achieve a low settled density, very low shear strength, and will be very compressible, demanding large, costly storages to contain the same quantity of tailings as other storage methods.

▸ SOLUTIONS

P.1 ■ Solution

1. False. The soil used in cutoffs and cores must have small permeability. It is intuitive that the higher the clay percentage, the less permeable the soil will be by default, and the less compaction effort will be necessary. Nevertheless, it is a fact that the upstream shoulder does not require highly impermeable clays as these would lead to undesirable uplift pressures developing beneath that section of the embankment.

2. True. Indeed, this is stated in USACE EM 1110-2-2300. In dams built upon impervious soils with flat embankment slopes, the water gradients may be sufficiently low to prevent failure due to piping and thus allow the engineer to control seepage without the need for vertical or horizontal drains. Projects conceived in this fashion include the Aquilla Dam in Texas, built by the US Army Corps of Engineers in 1983, and the Ray Roberts Dam in the same state, also operated by the USACE. The standard that specifies this design possibility remarks that a horizontal drainage blanket under the downstream embankment may still be required for underseepage control.

3. True. If the outer zones of the downstream slope are made of lightweight coarse materials, such as sand and gravel, they should be covered with rock or cobbles to prevent damage from wind or rainfall erosion. Outer downstream zones made from harder materials generally do not require additional protection.

4. True. Indeed, the use of slake-susceptible rocks such as siltstone or claystone does not prevent them from being a viable source of rockfill, provided they are well-compacted and watered during the compaction process. Fell et al. reason that there should be no special requirements on the durability of the rockfill, with the exception of some volcanic and altered granitic rocks that can deteriorate of over time. In contrast, riprap and the outer layer of the downstream slope may be more involved to design, and should have their durability under wetting and drying specified.

5. False. The statement would have been true had "rubber-tired roller" been replaced with "sheep's foot roller." The sheep's foot roller compresses the soil in such a way that the tamping foot action breaks up pieces of cemented soil or weathered rock in the fill. Other advantages include the fact that there is less of a

tendency for formation of large shear surfaces beneath the roller when a tamping foot roller is used, and, additionally, the fact that the compaction water content is less critical than for rubber-tired rollers (i.e., the shape of the dry density-water content curve is broader for sheep's foot rollers). Still, there are circumstances in which other types of roller may be more suitable, as in the case wherein water contents are naturally high and compaction is required at well above optimum water content; in such instances, use of a rubber-tired roller may be advisable since it is less likely to become clogged with wet, sticky clay.

6. False. In small dam practice, pipe drains should be employed only when used in conjunction with a horizontal drainage blanket or pervious zones. Reliance should not be placed solely upon pipe drains because the pipes can clog as the result of improper filters, root growth, or deterioration. This is also stressed in USACE 1110-2-2300, which notes that "collector pipes should not be placed within the embankment, except at the downstream toe, because of the danger of either breakage or separation of joints resulting from fill placement and compacting operations or settlement, which might result in either clogging or piping." The same text remarks, however, that a collector pipe at the downstream pipe may still be provided within a small berm is located at the toe, since this facilitates maintenance and repair.

7. True. Indeed, the primary cause of failure of embankment dams in the US is overtopping due to insufficient spillway capacity. Dam failure analyses in the US intensified after the failure of the Buffalo Creek Dam in West Virginia in 1972. Since this incident, there has been considerable effort in the area of dam monitoring, including the development of an inventory and the conception of the Dam Safety Program, in 1996, under the coordination of the Federal Emergency Management Agency (FEMA). Furthermore, it is a fact that seepage through the foundation of a dam is a greater problem than seepage through the dam.

8. True. The spillway is the main structure responsible for withstanding flood flows in the embankment dam. To ensure its optimal performance, specific measures must be taken, such as endowing an earth spillway with a creeping grass cover. Earth spillways have considerably smaller allowable velocities and discharges than those built on rock.

9. False. The frequency level of an elastic long and uniform triangular embankment section in general falls *above* 1 Hz, thus coinciding with the range of frequencies most often associated with earthquakes. A concrete dam, by comparison, will typically have f_n > 10 Hz, and will thus respond to seismic activity as a "rigid" body.

10. True. Indeed, instability of the downstream slope, be it because of excessive steepness or a high phreatic surface, is easily counteracted by provision of a berm of free-draining fill, such as a rockfill.

P.2 ■ Solution

According to the ICOLD, a dam with height between 10 and 15 m may be considered large if (a) its crest length is at least half a kilometer long; (b) the reservoir has a capacity no smaller than one million cubic meters; (c) the dam is of unusual design or had particularly difficult foundation problems (the ICOLD has included this norm so that innovative designs can be included in their bulletins and studied by designers of large projects). The fourth criterion is that the maximum flood discharge should be at least 2000 cubic meters per second, not 1000 m^3/s.

► The correct answer is **C**.

P.3 ■ Solution

The availability of a considerable portion of fine-grained overburden and the ample width of the site definitely favors the construction of a relatively flat earthfill embankment, owing, among other reasons, to the close availability of impervious construction material and general ease of construction. If the overburden material were scarce, a rockfill or concrete dam may have been a better choice (particularly, in the latter case, if the underlying rock were easily accessible; the availability of rockfill may dictate the final decision). In a narrow valley with steep sides and little overburden, an arch or cupola concrete dam, with their inherently high strength, may be more stable than a steep-sloped rockfill dam.

► The correct answer is **A**.

P.4 ■ Solution

Karst is a term used to describe a formation in which limestone bedrock has eroded in an irregular manner. The irregular erosion is caused by dissolution of limestone, which occurs as water is transported through the rock. Consequently, these areas are often characterized by extremely variable rock surfaces, rock pinnacles, solution channels, sinkholes, and caves that may not be able to adequately support the dam foundation. It is a travesty to say that the engineer can ignore the need to use intense grouting when building dam foundations in such materials, as they would otherwise provide unreliable conditions in terms of both hydraulic conductivity and mechanical strength.

▶ The false statement is **C**.

P.5 ■ Solution

Rolling the surface prior to insertion of the filter is in fact a poor choice, as it will destroy the soil structure and reduce the permeability, making it more difficult for seepage water to flow into the filter drains. The same applies to rocks, particularly the most friable ones. On low strength foundation materials, even traffic of earthmoving equipment will appreciably break up the surface, necessitating a "final cleanup" with an excavator or backhoe working away from the cleanup area.

▶ The false statement is **B**.

P.6 ■ Solution

According to the study conducted by the USBR in the late 1980s, dams with dumped riprap failed in 5 percent of cases, mostly due to the improper size of stones. Hand-placed riprap failed in 30% of cases in which it was used, and concrete pavement in 36% of cases. The use of dumped riprap was shown to be viable even when it required transportation over long distances (as much as 170 miles for some USACE projects). When the nearest source of suitable rock is far from the site and/or only small quantities are needed, it may be economical to use hand-placed riprap despite its higher unit cost for labor and material. As noted by Fell et al., the riprap used as protection should be large enough to withstand the impact of waves without being displaced, and strong enough to do this without abrading or without breaking down to smaller sizes. Rock types that are commonly used when fresh include quartzite, sandstone, limestone, granite, basalt, and gneiss. Most rocks containing siltstone, shale and claystone would be unsuitable for riprap because they would break down (slake) under repeated wetting and drying.

▶ The correct answer is **A**.

P.7 ■ Solution

Carbonate rocks are in fact a bad choice for filter material, as they easily tend to break down with subsequent loss in permeability. In addition, they are quite susceptible to dissolution when exposed to acidic environments, be it from the adjacent soil or due to foreign substances introduced in the well to counterbalance incrusting groundwater. The other alternatives are all provisions and statements found in Chapters 6 and 7 of USACE's EM 1110-2-1914 document, *Design, Construction, and Maintenance of Relief Wells*.

▶ The false statement is **D**.

P.8 ■ Solution

The measures stated are efficient approaches to strengthen the dam against seismic activity, with the exception of D. The engineer should have the dam crest be as wide as possible so as to better distribute stresses emanating from seismic waves. Other viable measures recommended by the US Army Corps of Engineers include flaring the dam at abutments and increasing the width of filter and transition zones adjacent to the core.

▶ The correct answer is **D**.

P.9 ■ Solution

The answer becomes obvious if the student recognizes that the term "suffusion" is often used as an equivalent phrase for "internal instability." As mentioned in the paragraph, a soil's susceptibility to suffusion is commonly associated with specific particle size distributions, as it is particularly common in broadly graded soils with particles from silt or clay to gravel size, soils with particle size distribution curves that are concave upward, and gap-graded soils. Suffusion occurring within an embankment core or the foundation of a dam will result in a coarser soil structure, leading to increased permeability and seepage, likely settlement of the embankment, and a higher likelihood of downstream slope instability, possibly culminating in dam failure. A filter constructed of internally unstable materials will have a potential for erosion of the finer particles, rendering the filter coarser and less effective in protecting the core materials from erosion, and ultimately leading to piping failure.

▶ The correct answer is **B**.

P.10 ■ Solution

Due to poor construction techniques, the core may have been compacted comparatively more than other parts of the embankment. As a result, the upstream and downstream sides or shoulders of the embankment settle more than the core because they are less well-compacted and, as the foundation is firm and cannot fully absorb the differential settlement, cracks appear along the crest edges while the settlement takes place. These cracks usually do not constitute a serious problem, and can often be treated by ramming in damp soil complete with grass as soon as they begin to develop. It is important to prevent water from entering (otherwise erosion and waterlogging will follow) and in the rainy season it may be necessary to sandbag the area to minimize runoff.

▶ The correct answer is **C**.

P.11 ■ Solution

The most common approach to protect a conduit against piping is to provide it with a concrete collar, widening the seepage path needed for water to penetrate the pipe and shielding it from stress-induced cracks. The other alternatives are either ineffective or even harmful. Even in small, homogeneous dams where no chimney drain is installed, it is advisable to provide a drain and filter around the conduit at its downstream end for the purpose of intercepting concentrated leaks that follow the conduit. (Consequently, not placing the conduit close to filters, as indicated by A, may only worsen its hydraulic interaction with the environment). Similarly, use of multiple small conduits, as suggested in C, is expensive and will only disrupt the embankment structure further, providing shorter seepage paths and more complex stress distributions. Statement D is also false, as there is no evidence that joints are particularly susceptible to piping, because, after all, this characteristic is more dependent on the environment *surrounding* the conduit than on the geometry of the conduit itself. Finally, it should be noted that the use of concrete collars, albeit common, is far from being an optimal solution to shield conduits from piping action. Indeed, the participants of a 2000 ASDSO-FEMA workshop on seepage through dams were unanimous in agreeing that cutoff collars should not be provided, because they make compaction more difficult. See Fell et al. for details.

▶ The correct answer is **B**.

P.12 ■ Solution

The fact that tailings offer greater resistance to flow (i.e., are more viscous) than water does not imply that freeboard and overflow capacity can be lowered, although this has been done in several cases. Other malpractices include poor control of the internal seepage regime and excessive downstream slopes with marginal stability. The other alternatives are correct: A is a fact of tailings dams

practice, which are often subjected to poor quality control; C is also correct, as tailings dams tend to be raised sequentially, which is a permissible approach provided the incremental raising is properly engineered and controlled; finally, D is an accurate definition of sub-aqueous deposition.

- The false statement is **B**.

ANSWER SUMMARY

Problem 1	T/F
Problem 2	C
Problem 3	A
Problem 4	C
Problem 5	B
Problem 6	A
Problem 7	D
Problem 8	D
Problem 9	B
Problem 10	C
Problem 11	B
Problem 12	B

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