TC304-TF3 COUNTRY REPORT

on
Troublesome Ground and Correspondence Technology
in Underground Construction
in Japan

Country
Japan

Period
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CONTENTS

Disclaimers

Preface

- It becomes a common view that it is important to study the Geo-Risk during the construction stage in Japan, expecially those could lead to some serious troubles or accidents. One research committee, "Geo-risk Society" in Japan, started in a few years ago, mainly made the efforts at a proper plan on the geological investigation technologies and their utilization to mitigate the geological risk. Also, Kansai branch of JGS (the Japanese Geotechnical Society) set up "Research Committee on Characteristics of Troublesome Ground and Correspondence Technologies in Underground Construction" in 2011 (chairman: Tadashi Hashimoto, Geo Research Institute, Japan). The concept named as "Troublesome Ground" has been accepted in Japan, refering the grounds in whick troubles and accidents, such as inflow, piping, liquefaction, large deformation, landslide etc. happened relatively often.
- Here, we would like to introduce some research activities made by this research committee in the period of 2011 to 2013 on the characteristics of troublesome ground and correspondence technologies for the troubles in underground constructionduring, mainly based on the cases in Kansai area of Japan.

1 Introduction

- It is difficult to construct underground structures in particular soft ground such as fine sand with low uniformity coefficient, gravel or cobble with high groundwater head, etc. Troubles, even seriors accidents, such as great inflow of ground water composed lots of soil paticles, collapse of diaphragm wall or cutting face of tunnel, large settlement in ground surface due to the excavation, etc. occured in these kinds of ground relatively often. We named these kinds of soft soil ground as "the troublesome ground", which is certainly not rare in large cities in Japan, where the high groundwater level makes the situation stricter. Moreover, associated with the development of underground space, constructions have to be progressed in great depth underground space, or have to be conducted in congested space with complicate adjacent condition. These make the underground construction becoming more difficult. This tendency can be found in large cities with similar ground condition such as Osaka, Nagoya, Tokyo in Japan, as well as large cities in other countries which are built in the area along shore, such as those in China and the Netherlands.
- In Japan, it becomes necessary to hand technical capabilities down to the next generation, because opportunities to be involved in a plan, design or construction of project in large-scale, or with difficult construction have been decreased due to the reduction of construction investment in recent years. Therefore, troubles could also come from the lack of knowledge nor experience on the construction technology in future. And also, it is important to disseminate the information concerning with the knowledge learned from many experiences with troubles in Japan to the world, including prosperous Asian countries with similar ground condition.
- For these purposes, Kansai branch of JGS (the Japanese Geotechnical Society) set up "Research Committee on Characteristics of Troublesome Ground and Correspondence Technologies in Underground Construction" in 2011. This committee collected cases of trouble which affected underground construction in many troublesome grounds, made the efforts at exploring the possibility of geology or soil property approaches such as depositional environment of the ground and its physical properties, and carried out the research on the causal relationship among them and then researched on the effects on risk management for the trouble. The committee consists members of senior experienced to young engineers from owner, contractor, consultancy and geological investigation companies, members of researchers from universities and institutes, also including overseas members.

2 Classification of the troublesome ground in underground construction and kinds of trouble

- The troublesome ground for underground construction includes fine sand layer, cobble, cracky clay, sensitive soft clay, buried obstacls such as wood pieces, mixed face ground (the case where hard ground and soft ground are intermingled to cutting face). Especialy among these grounds, the fine sand with low uniformity coefficient and the cobble with high groundwater head are more potentially to cause some troubles in underground construction progression.
- In fine sand ground, the inflow problem occasionally occurs accompanied with piping phenomenon from the excavation bottom of open cut work, or through some small lack in cut-off wall, or coming from the screw conveyor gate of EPB (Earth Pressure Balance) type TBM (Tunnel Boring Machine), since it is easy to liquefy even with small gradient of groundwater head. In consequence of liquefaction, resistant force of ground decreased obviously, and adjacent underground structure could be damaged in serious. Collapse is also a serious trouble often occuring in cutting face of slurry type of TBM tunnel work, or in the wall of trench, due to the instability of this kind of ground. Moreover, when boring a tunnel in this kind of gound, the boring machine could be trapped in this squeezing ground. This difficult situation is exacerbated by the less effective of the dewatering method nor the chemical grouting method in fine sand ground, especially in the case when the sand particle diameter is very small and coefficient of permeability is as low as k=1x10-4 (cm/s).
- In a condition that a fine sand layer deposited over a gravel layer with a high value of permeability coefficient, the risk of seriors accident could be more higher. Amount of sand particals could be washed out by groundwater flow, cave-in could take place in ground in consequence.
- On the other hand, in a cobble ground, there are 4 problems. ①Insufficient quality of diaphragm wall. ②Insufficient quality of ground improvement by Jet Grout Pile (called JGP) and chemical injection grouting ③Inflow problem in the cutting face of TBM by the difficulty of discharging the excavated soil. ④Breakage and wearoff of cutter head of TBM

3 Depositional environment and characteristic of the troublesome ground

- The depositions of sediment by the river, sand, gravel and clay, etc. are related to conditions such as the flow velocity of river depending on the geographical feature at the time of deposition. For example, in the case of the Osaka plain, layers of sand, gravel, and clay deposited alternatively along the depth until the strata at a depth more than 1000m, which are called the “Osaka layer group”, by the sea transgression and regression due to the worldwide temperature variability. Many clay layers deposited on the sea bed during transgression pieriod called “marine clay”. Fine sand layers are often found on the upper and lower sides of the marine clay near the estuary where the river flows slow. Gravels and cobbles are deposited at the upper stream of a river with high flow velocity in many cases. Depend on the phenomenon of the deposition of soil, the deposition area and depth of fine sand and gravel or cobble as a troublesome ground can be specified to some extent.
- Regarding the depositional environment of fine sand, it is common not only in Osaka and Tokyo but also in Shanghai, Tianjin in China and some cities in the Netherlands, etc. which are located in the estuary of a large river. On the other hand, the depositional environment of gravel and cobble is near the upper stream where the river flows fast, near the fan at the foot-of-a-mountain part, such as the area between Osaka and Kobe, Kyoto basin, and Shiga etc. in Kansai. Cracky clay is mainly seen in the flexure part of Osaka layer group, sometimes with a slickenside. The stability of a cut surface in this cracky clay layer is easy to be spoiled. In the lowland of East Osaka, a very soft and sensitive alluvial clay is deposited in the lagoon in several thousand years. As the sensitive clay has high liquidity index about I_L=1 and its strength reduction by disturbance, due to construction, is very large.
- The typical troublesome fine sand in Osaka plain has the nature that the fine-grain fraction content of particle with size smaller than 74μm is less than 10%, the uniformity coefficient Uc is less than 5, the coefficient of permeability k is less than 10^{-3} (cm/sec). Moreover, it has the characteristic that even small hydraulic gradient could cause a boiling easily with the groundwater flow.

4 Case study of trouble in open cut work

- In many cases of inflow during the open cut works, piping phenomenon occured in the fine sand layer. Accompanied with great inflow of groundwater, sand particles or soils were also flowed in. Here, four kinds of inflow in open cut works are shown below.
  - ① The inflow passing through the weak parts such as a low quality joint or other defective part of cut-off wall.
  - ② The infiltration flow passing around the lower end of the cut-off wall.
  - ③ The inflow along a remained bore hole and an old well, etc.
  - ④ The inflow through a lack of the soil improvement work, such as JGP and chemical injection grouting, etc.
- Fig.1 (a) shows a flaw in cut-off wall appeared in a location between an upper clay layer and a lower sand layer. Even if the excavation depth has not reached the lower sand layer yet, it is also very possible that an inflow takeplaces, as shown in Fig.1(b) for example. In the case that a fine sand layer deposited upon a gravel layer with high permeability, the fine sand will flow with groundwater, and scouring effect will happen gradually, then it will result to the inflow composed with a lot of fine sand.
- Related to ②, inflow with piping might be caused by the shortage of the installation depth of the cut-off wall, because of lacking in ground information, for example, as shown in Fig.2. In the case of encountering a complex ground condition, it is necessary to conduct detailed geological investigation which focuses on the continuity of the stratum and insite pumping test in the purpose to grasp the sealing effects of a cut-off wall or ground improvement before the excavation work.
- There are many examples of inflow along remained bore holes or existing wells stated illustrated in Fig 3. To prevent this kind of inflow trouble, it is necessary to gather as more as posible the information on existing bore holes and wells, to take measure as much as possible for example sealing the existing bore holes by grouting. Moreover, it is necessary to require filling in of the borehole and well by thoroughly using seals material at the time of site investigation.
- JGP is often employed in the soil improvement to patch up the defective part of cut-off wall or as a countmeasure against uplift of an excavation bottom. It is not rare that an inflow occurs through the defective part or the lack of improvement illustrated in Fig4.
- In order to cover this issue due to the defective improvement of the JGP, to enlarge the thickness of improvement, to employ a higher ability of JGP, to employ chemical grouting as an additional improvement, to conduct insite test for examination of sealing effect, and as well as to improve the quality of JGP work will be necessary.

4.1 Case study of the inflow from retaining wall at underground construction site in Osaka

- A suddenly happened seriours inflow takeplaced in an excavatioon work for railway station in Osaka-city, in April 1992. Huge quatity of groundwater flew in when excavation depth at GL-21m. Although the construction was stopped immediately after the inflow takeplaced, an adjacent sidewalk sinked in with maximum depth of 30cm, over 2.5m in wide, and 30m long, and damage occurred in the neighboring private house etc.
- In this case study, following geological and hydrostatic conditions are considered to be related to the inflow accident.

- The groundwater leaked from the Tenma gravel layer just lying below the excavation level and also from the alluvium deposit in the upper part. The water head of the Tenma gravel layer is as high as GL-2m to -3m. Below the alluvium clay, there is a thin layer of fine sand whose particles are homogeneous and easily liquefied.
- It is concluded that there is a possibility that the confined groundwater contained in the Tenma gravel layer, leaked with fine sand from a joint of the retaining wall.
- As emergency measures, the most effective method in stopping the water leakage is to pour fresh concrete from bore holes behind of the retaining wall near to the location of inflow.

5 Case study of trouble in shield tunneling

- The following cases are mentioned as troubles of shield tunneling in a troublesome ground.
  - ① Collapse in the cutting face due to the blow from a screw conveyor
  - ② Collapse in the cutting face due to the imbalance of face pressure
  - ③ Inflow takeplaced in the vertical shaft during the launching and arrival of TBM
  - ④ Inflow from the week point during constructing a cross passage between the twin tubes
  - ⑤ TBM is Trapped in squeezing ground such as a fine sand layer
  - ⑥ Breakage and abrasion of the cutter in the cobble ground

5.1 Collapse in face ground due to the blow through a screw conveyor

- In excavating by EPB (Earth Pressure Balance) shield machine in a fine sand ground, it is difficult to condition the excavated soil in chamber or on screw conveyor. By accident, the excavated soil could blows in like quicksand from the discharge gate(as shown in Fig.5). If large ground loss happened, subsequent nose down phenomenon is possible to occur by the boiling at the surrounding ground, and finally the extremly rising of the pressure at the tail of the shield is possible to cause the segmental lining damaged. It could also results to great cave-in in surface of ground in the case of the intense blow accident.
- In order to prevent the occurrence of intense inflow, a water stop plug is to be formed sufficiently in a screw conveyor. It is useful for doring a tunnel not only in fine sand but also in gravel or cobble ground with high permeability.
- If cobbles are clogged in a screw conveyor, the excavated soil in the chamber can not be discharged without very fine materials with ground water as a result, a ground cave-in.
- And in the case of a mixed face ground, there is a sand and gravel layer on a hard rock at a face, excavating tunnels may take a long time and then due to the disturbance of the upper sand layer, it results to collapses.
- As a countermeasure against above troubles, it is recommended that to employ sealing material to a screw conveyor and chamber, to enlarge the diameter of the screw conveyor, and to mount a crashing equipment at a cutter face for the cobble.

5.2 Collapse in the cutting face due to the imbalance of face pressure

- The imbalance of face pressure occur in a gravel ground with high permeability because the lost circulation due to slurry seeping out into the ground at face, and also occur in a fine sand with low permeability because the mud film at cutting face is very thin, and could be shaved off easily. The imbalance of face pressure causes a collapse or large settlement of ground in front of the TBM. It is effective to employ relatively dense slurry.

5.3 Inflow in the vertical shaft during the launching and arrival of TBM

- Although ground improvement could be carried out at the launching and arrival of TBM by JGP, chemical injection grouting method, or freezing method, etc. the inflow of ground water containing fine sand may often occur because of the damaging in of the impervious wall

- or the improved ground as shown in Fig. 6. As a countermeasure, it is recommend to conduct the additional chemical injection grout, as well as performing strict execution management.

5.4 The case of inflow while constructing cross passage

- An accident of inflow in tunnels and a subsequence collapse of suronding ground and structures right above estructed tunnels occurred in Shanghai metro No 4 line on July, 2003, during the construction of a cross passage between completed twin tubes.
- The freezing method was employed as soil improvement to build a cross passage in a fine sand layer with high ground water pressure at the depth of GL-35m. Just before the excavation of cross passage to be completed, a inflow occurred from unfrozen area.
- As a result of this inflow, over 200m tunnels collapsed by the surrounding soil carried out boiling. The broken segmental lining settled out about 5m at the maximum from the original depth. It is great experiences that the excavation of a cross passage in a layer of fine sand by the mining method has large risk. In order to reduce the risk of inflow which could cause a big accident, the reliability of soil improvement should be implemented.

5.5 Being trapped in squeezing ground

- It is often seen the trouble that the TBM is trapped in squeezing ground, during the boring in fine to medium sand with a small uniformity coefficient. The phenomenon caused by an increase of frictional resistance between a shield and the ground as shown in Fig.7. in consequently, extremly raising reaction force according to the large thrust jacking force caused in large deformation and damage of segmental lining, and the advancement speed of TBM is to be decreased for the shortage of excavation thrusts.
- As a countermeasure, it is effective to inject lubricated material into the gap behind the shield body, to make overcut more. It is also necessary to design more powerful TBM and lining when encounting these kinds of troublesome groundss.

5.6 Breakage and abrasion of the cutter in cobble

- Although it can be excavated by the teeth cutter in the clay, sand, and gravel, it is difficult to excavate in the cobble ground with large stones, because the teeth cutter could fall or be damaged, or be excessive abrasion. It is also a strict problem to be the excessive abrasion or breakage of disk cotters in excavating cobble ground. As a countermeasure, it is required to equip disk cutters and shell bits, or to use exchangeable cutters.

6 Tendency of the trouble and its countermeasure

6.1 Tendency of the trouble

- In the latest underground construction in large cities in Japan, the risk of inflow troubles was increasing since the pumping regulation released in the 1970s which originates in the groundwater level rise, the increase of the utilization of deep underground space, and the congestion of underground structures. Although the dewatering method had been used as one of the effective countermeasure against the inflow trouble before 2000, it has been difficult to adopt this method due to the restrictions on environmental problems, such as land subsidence by a groundwater level fall, and drying up of existing wells.

6.2 Countermeasure for the trouble

- Therefore, it has been common to install the cut-off wall deeper, or accompany with a ground improvement around the excavation area by JGP or chemical injection grouting in the open cut work to build an impervious wall or ground.
- As to the countermeasures, the adoption of the highly impervious cut-off wall and the new technology of ground improvement are developed in recent years. For example, there is a new Trench cutting Re-mixing Deep wall method (TRD), by which trench can be excavated continuously by a chain saw, and build soil cement mixing wall without joint. Moreover, it is also an effective method for especially deep excavation using a remote control type shovel machine in pneumatic caisson method which has been applied often recently.
- On the other hand, the closed type of shield tunneling method has been often adopted in urban areas without any trouble except in the troublesome ground that involves gravel ground, cobble ground, fine sand, and sensitive clay etc. In particular, it is seen that the blow due to the blockade of a screw in cobble ground, the instability of cutting face due to on fine sand, the subsequent subsidence due to the disturbance of the ground on sensitive clay. However, it seems that there are still many inflow troubles in the case of construction of the launch and arrival vertical shaft, a cross passage between tunnels and enlargement of the existing tunnel by mining method. As countermeasures to these, it is important to raise the quality of ground improvement and build up the more accurate examination system for the impermeability of cut-off wall and ground inprovement.

6.3 Site investigation for the troublesome ground

- Moreover, it is also very important that we should consider sufficient site investigations such as obstacle investigation and the geological survey, not only before construction but also under construction, and should consider the utilization of the observational methods.
- It is important to grasp the 3D geological profile with groundwater information, as well as to understand the geotechnical properties of soils for the underground construction in urban areas.
- Before the site investigation, it is effective to study the formation process of the ground based on geological and geographical feature firstly using the database of the ground in order to grasp a wide ground condition.

- Although boring survey and penetration tests are often used for the site investigation, these results acquire only the scarce information on the limited area. So, it is recommended to use the geophysical exploration simultaneously, such as sonic wave.
- The observation of the core obtained by the continuous sampling gives the most important information for the underground construction, including the observation of the stratification condition, permeability, hardness, density, sensitivity of clay, and potential crack state in ground such as sand, sand gravel, silt, and clay, etc..
- In order to investigate the hydraulic characteristics of aquifers such as the permeability, the influence radius and the groundwater pressure, it should be carried out a multi-well pumping test which is commended by the markedly high accuracy.
- It is important to carry out additional site investigations suitably during construction period to improve safety for the unforeseeable varied ground.

7 Postscript

- In recent years, an opportunity for a young engineer to engage in large-scale and difficult underground construction has decreased, since large-sized construction project like a subway construction is also decreasing in Japan.
- Moreover, it is time for many experienced senior engineers to retire at once from the practical work. Therefore, we believe the knowledge tradition on the underground construction is to be advanced by learning troubles and its countermeasure together with senior and younger engineers.

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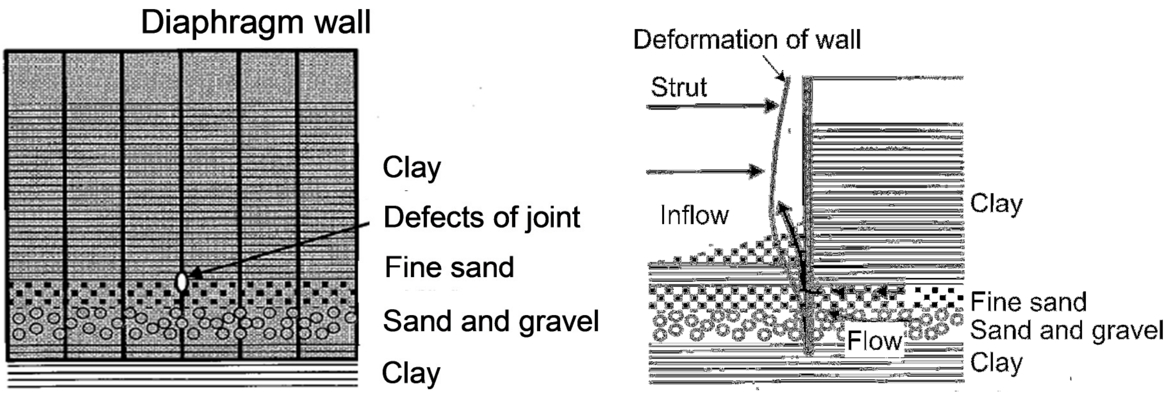

a) defective part at the joint b) inflow occurred at the defective part

Fig 1 Inflow occurred by defective part in cut-off wall

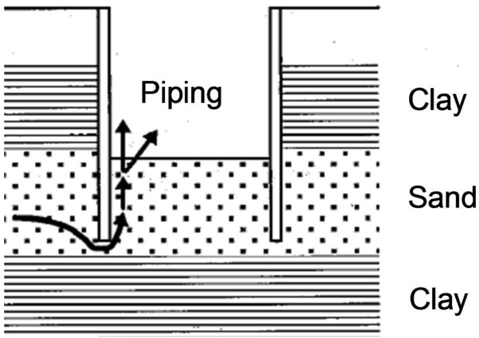

Fig 2 Inflow caused by shortage of installation depth of cut-off wall

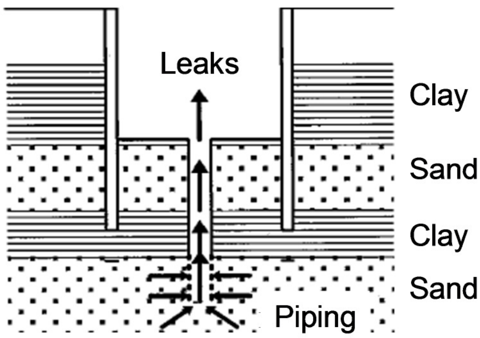

Fig 3 Inflow caused by fail sealing of bore hole or existing well

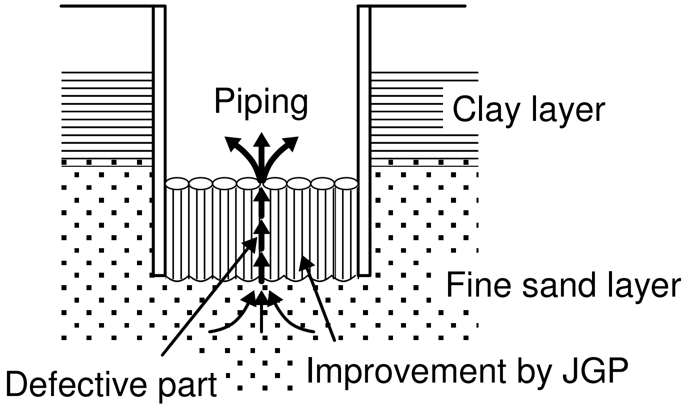

Fig 4 Inflow caused by defective part of soil improvement by JPG

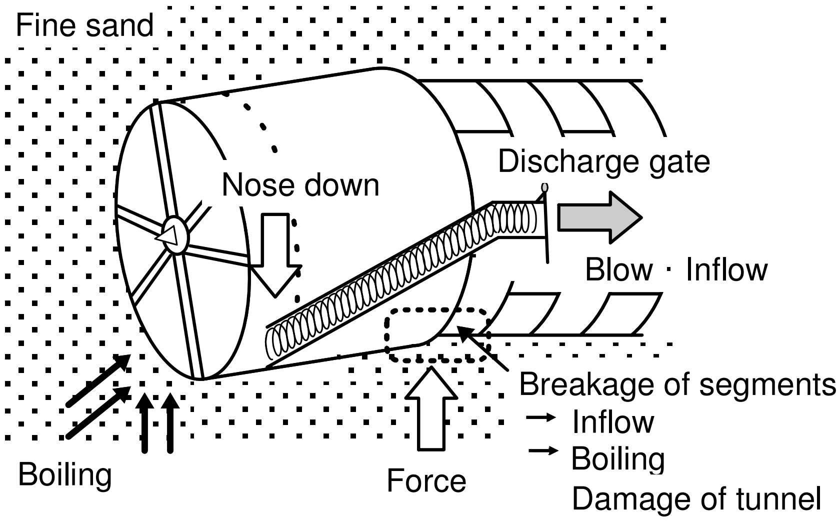

Fig 5 Inflow through discharge gate

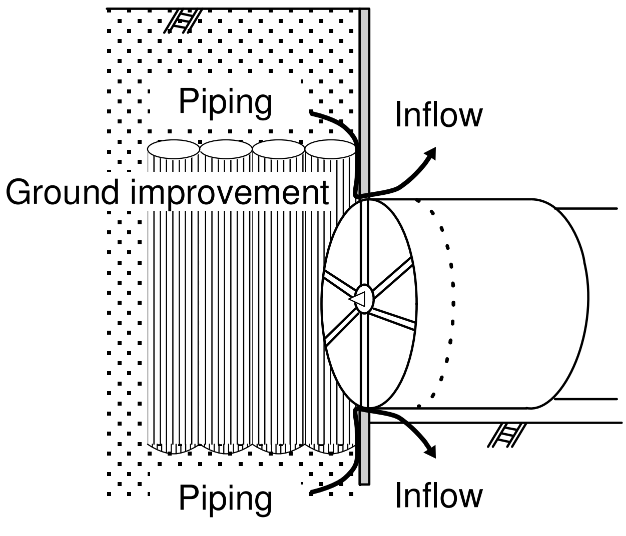

Fig 6 Inflow at langch / arrive shaft

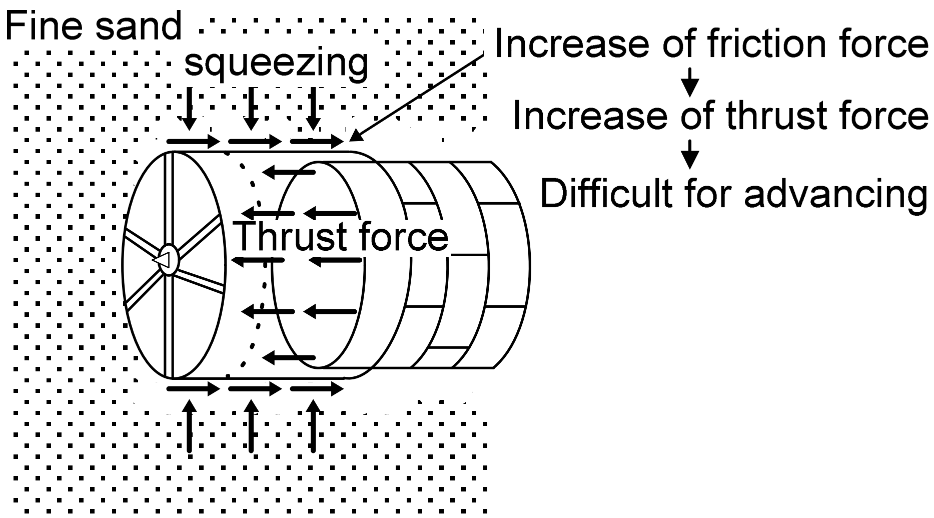

Fig 7 Being trapped in squeezing ground of fine sand