TREND EDITORIAL

Survey and research frame for ground sediment

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Sediment from the fine particles forming rock fragmentation is composed of soil and sand. Sediment is carried by water into the river and sea and silt rivers and ports. Sediment taken into the air by wind becomes the dust and haze. Sediment has been closely linked with the human life, and forming many disasters more closely impacting the human life. Sediment is mainly from the land and river, as well as sediment from the underground called "ground sediment." Sediment, hidden in the underground, is not known to people. The sediment particle transport in soils by water scouring can be found in the reference Sun (2016). Some or one soil particle runs in a crack and passageway between soil particles. In the process, soil particles perhaps form new structures or passageways. Ground sediment deeply affects human life, such as sediment attracted and driven by the water is becoming the heaving pit (Fig. 1a.), heaving mound (Fig. 1b.), heaving mound on Mars (Fig. 1c.) and some riverbanks collapse (Sun 2014a, b); while the ground sediment transport can also cause damage and collapse of the riverbank and embankment, building, and ground subsidence. The current studies are less involved in the transport and movement of the ground sediment. Therefore, strengthening the ground sediment study has an important, practical, and theoretical value.

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Three levels of sediment

The former research on the sediment is focused on river sediments as shown in Fig. 2a,, which are studied in the river in order to obtain the river ability to erode sediment, the sediment distribution along the river length, and the depth. Research from previous years has risen from the river channel to the land, that is from the river channel sediment (as shown in Fig. 2a.) to the land sediment (as shown in Fig. 2b.). One typical research of this is the digital watershed model (Formetta et al. 2014). It takes the sediment movement driven by the rainfall as the main research contents to obtain the erosion spatial and temporal distribution. Many researches (Cessna et al. 2006; Odgaard 1993; Riccio et al. 2014; Serno et al. 2014) focused on the wind sediment, which is driven by wind and belongs to the surface sediment.

The latest research will further improve the sediment research content. The surface sediment is extended to the ground. One part of the river sediment is from the river bottom and sides, and the other part is from the land surface, the watershed sediment studied, the sediment of which is located on the earth surface; and. therefore, can be called surface sediment, as shown in Fig. 2a, b.. There is also a significant source of sediment: internal riverbank and under land, which is from the underground and can be called ground sediment (Sun 2015, 2016; Sun & Wang 2013; Wang et al. 2010, 2011), as shown in Fig. 2c.. Research on ground sediment is a new research area, and the typical performance in this area is the riverbank stability reduction and collapse by the ground sediment transport under the scouring and the fluctuation water level.

The ground sediment existence and transport can cause a lot of engineering problems, as shown in Fig. 3. The ground sediment transport under the fluctuation water level in

Fig. 1 The Ground uplift caused by ground sediment transport. **a** Milwaukee road heaving pit. **b** Pingo on the earth. **c** The pingos on Mar HiRISE image: ESP-014,413-2065

riverbank may eventually lead to the collapse of the dam embankment. The groundwater with the changing level drives the ground sediment transport leading to the ground subsidence. The heave driving sediment transport causes the heaving mound to grow, as shown in Fig. 1b and collapse as shown in Fig. 1a.. Heaving mound is found not only on the earth but also on Mars (Burr et al. 2009; de Pablo and Komatsu 2009; Dundas and McEwen 2010), as shown in Fig. 1c. Sediment in faults and fractures under the external disturbance, such as earthquakes and water level fluctuations, is transported. This transportation leads to the activation of faults and fissures. The groundwater exploitation driving the ground sediment transport leads the groundwater fissure to be blocked and to prolong the water supply. The ground sediment transport with the water and oil leads the oil fissures to be blocked and cause the oil flow velocity to decrease, etc. These are likely to lead to

some major accidents or increase the running costs, which are directly related to the underground sediment transport.

Sediment transport in unsaturated soils

Soils can be classified as saturated or unsaturated based on their water content. The ground sediment transport has two types, sediment transport in saturated and unsaturated soils. Sun and Wang (2013) studied the sediment transport in soils and established the transport model of ground sediment in soils. This model starting the mathematical model from the ground sediment concept is the stable sediment transport in saturated soils. The model is very significant. Rising or falling river water levels cause water to move laterally to or oppose the riverbank. Rainfall causes water to infiltrate into soils. The rising or falling ground water level causes water to move up or down. The migration of water in soils changes the water content. The ground sediment movement carried by water is called the water and sediment movement in unsaturated soils. These physical phenomena, called forward and reverse movement of water and sediment, are related to the reciprocating movement of water and sediment in horizontal and vertical direction.

The ground sediment reciprocating transport contains the soil damage and recovery. Sediment erosion in water results in the loss of soil, so the porosity in sand position increases and the intensity and strength reduce, which can be called damage. When the water flow direction is reversed and the sediment movement is reversed, the original soil strength is enhanced, which can be called recovery (Kakuturu & Reddi 2006),
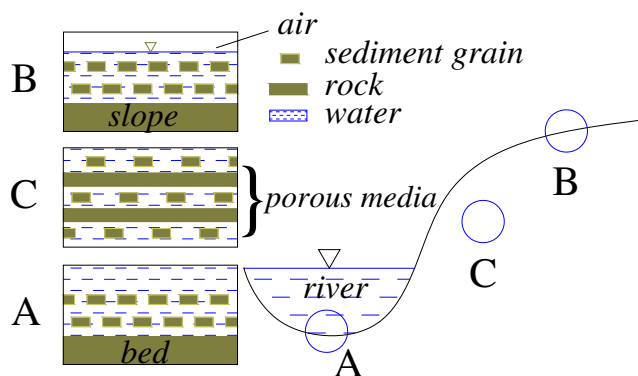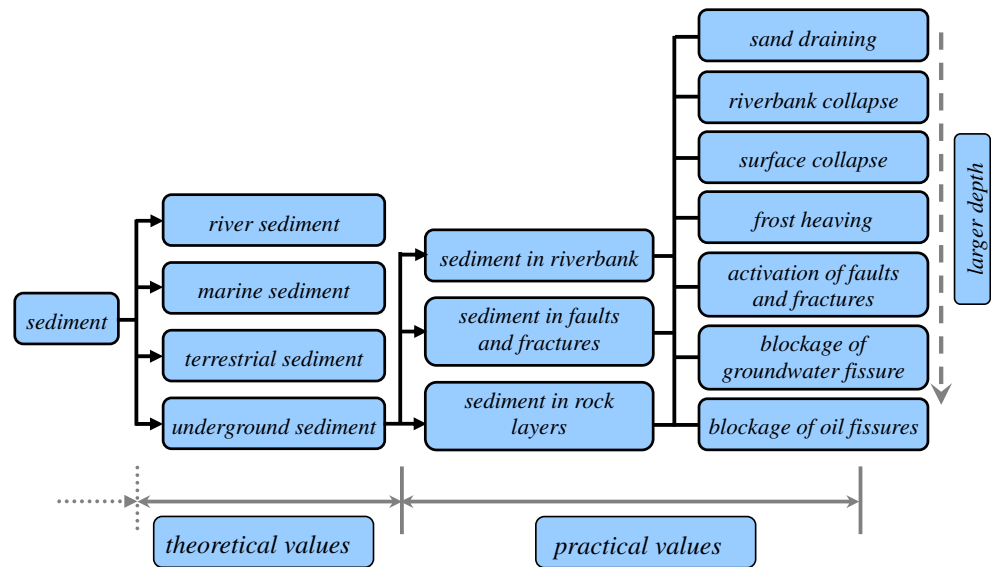

Fig. 2 The three levels of ground sediment. **a** River channel sediment. **b** Surface sediment. **c** Ground sediment

Fig. 3 Classification of sediment and engineering problems

because the strength where the sediment gathers is higher than the location of the sand sediment washed away.

Research on sediment transport in the unsaturated soil contains the unsaturated soil infiltration and sediment transport.

Studies on unsaturated soil infiltration have made great achievements. The Richards equation is obtained in the study of the fluid capillary conduction in porous media (Richards 2004). The following researches are based on the equation (Guerif et al. 2001). References (Topp et al. 1980) obtained the permeability coefficient by fitting and taking moisture as a variable. In the paper (Van Genuchten 1980), the water pressure and moisture can be taken to build a function to determine the relative hydraulic conductivity. Some recent studies focused on the following aspects: (1) The method of solving equations, such as the finite element calculation (Tayfur et al. 2010a, b), (2) the solute and water content measurement studies on site (Reichman et al. 2011; Stumpp & Hendry 2012), (3) unsaturated soil monitoring methods (Saintenoy & Hopmans 2011), (4) solving theory (Sun & Wang 2010), (5) the effect of temperature on water flow (Jahangir & Sadrnejad 2012; Sun et al. 2006), and so on. These are the theoretical or experimental researches of the Richards equation parameters.

Researches on the sediment transport in the unsaturated soil are few, but are mainly concentrated in the river sediment study. On the sediment particles transport in water, major research papers are (Einstein 1950; Qiwei 2007). These studies greatly founded the basement of the non-uniform particle sediment transport researches, and ingeniously explained the different size particle movement of sediment scoured by river water. The practical applications of these theories include the river channel sediment start (Yang et al. 2009), the sediment saturation and numerical simulation (Guo et al. 2012), and the watershed sediment (Li et al. 2012). These studies can provide the important reference value for unsaturated soil sediment transport studies. The closest researches in this area are from Sun JC (Sun 2013; Sun & Wang

2013; Wang et al. 2010, 2011), who studied the process of the saturated steady water flow driving ground sediment, proposed the sediment transport equation, and obtained the sediment content evolution along the way.

Sediment transport studies in the unsaturated soil need to be focused on the breakthrough of the coupling relationship between the water flow and sediment transport in unsaturated soil, and on the proposed coupling parameters and equations, and on establishing high efficient numerical simulation methods. The reference (Sun & Wang 2013) studied the process of the saturated groundwater driving the ground sediment transport, obtained the sediment transport equation, and gave the numerical simulation. The author gave suggestion that some experimental equipment should be founded and further experiments should be made. About equipments testing saturated sediment has emerged, patents (Wang et al. 2010, 2011) give the direct method to measure the ground sediment transport after scouring and eroding. The patent (Sun 2013) presented the method and experimental concept in the process of the ground sediment blocking and dredging the rock fracture driven by the ground water. A comprehensive study can be conducted through experiments and numerical simulation in this area. Many research works (Davis and Fox 2009; Walling 2005) used the tracer method to study the source regions of dust, which obtained the success. The ground sediment research can reveal the geology phenomena, such as the rock and soil lay's distributions, connecting with the tracer method.

Fluctuating transport of ground sediment

Ground sediment involves a lot of physical phenomena and needs to be understood and scientifically explained, one of which is the fluctuation of the ground sediment transport.

Water, sand, and soil are involved in the interaction process between water and sediment. In the seepage process, the velocity is proportional to the hydraulic gradient, like the curve shown in Fig. 4a. meeting Darcy's law (Gutman & Davidson 1975) $v = k \triangle h/L$. $\triangle h$ is the flushing water pressure head, v is the flow velocity, k is the permeability coefficient, $\triangle h$ is the water pressure difference, and L is the path length of the infiltration from the inlet to the outlet.

Soils are made up of a lot of sand and sand particles between each bite mosaic with a certain strength. The seepage appears under the water pressure and meets *Darcy*'s law (Neuman 1977), according to which the flow velocity is proportional to the hydraulic gradient, as shown in Fig. 4. At this time, the mosaic resistance between particles is much larger than the water flow pressure (Espinoza and Santamarina 2010), so, there is only water seepage. With the water pressure increase, the water seepage erosion force increases. The tiny particles move with water when the erosion force becomes greater than the mosaic resistance, as shown in Fig. 4b,c., which is called percolation.

When the water pressure gradually increases, the fine soil particles pass through the pores between the large particles, and at this time the transport channel is not stable. The space vacated by the small particles carried away by water is a part of the flow channel. The space is so big that it causes the surrounding soils to be damaged and collapsed and the void ratio and flow velocity to increase (Indraratna and Radampola 2002), and at last, more particles go into the water flow.

In the course of the small particles first transport moving forward, if the particle diameter is bigger than that of the pore channels, small particles will clog the channel, and the water flow rate will be reduced, thereby, the sediment transport capacity will reduce. When sediment blocks the pore channel along the way, because the congestion is a gradual process, the resistance at the location of blockage increases. When the flow rate becomes zero, all the head pressure $\triangle h$ is applied to the clogging particles, and this blockage and cumulative water pressure increases gradually. When the water pressure is greater than the clogging particles resistance, the clogging particles will break through the blockage

and move forward. This process is different from the fluctuations in the river channel sediment (Mu et al. 1999). This pressure is an increasing and decreasing process with stages in terms of time and segments along the way, so the seepage water pressure is fluctuant. The water pressure at a point in terms of time also has a continuous fluctuating characteristics with accumulating and breakthroughs, so it can be called multi-amplitude sediment transport. Also, along the way, the sediment concentration and its change with time are also fluctuating, as shown in Fig. 4b. When the flow path is less than half a wavelength, it becomes the single amplitude sediment transport, as shown in Fig. 4b. In this transport process, there is no accumulated or clogging phenomenon, but the water pressure directly breaking through soils. Therefore, the single amplitude sediment transport is a special case of the multi-amplitude transport. Sun (2013, 2015) separately studied the mathematical model coupling seepage and sedimentation of solid particles in porous media and the experiment method. Sun (2015) established the block model of ground sediment by numerical example, which can analyze and explain the natural reason of ground sediment fluctuating transport, because the fluctuating transport blocks and dredges the crack and passageway one by one and step by step.

Dumbbell-shaped mode of the ground sediment transport

In the ground sediment transport process, the sediment and water seepages appear progressively, which is similar to the riverbank degradation (Rinaldi & Nardi 2013). We find that the outlet greatly impact on the water and sediment seepage, and even decisively.

In the process of the river water and sediment transport in the river, when water rises to break the riverbank, a new secondary channel and secondary river will be formed (He et al. 2013). In the same way, when the secondary river channel is broken, the new third river channel appears. In this process, the sediment is transported with water. This phenomenon is called river channel diffusion, as shown in Fig. 5a.

Fig. 4 Three stages of ground sediment transport
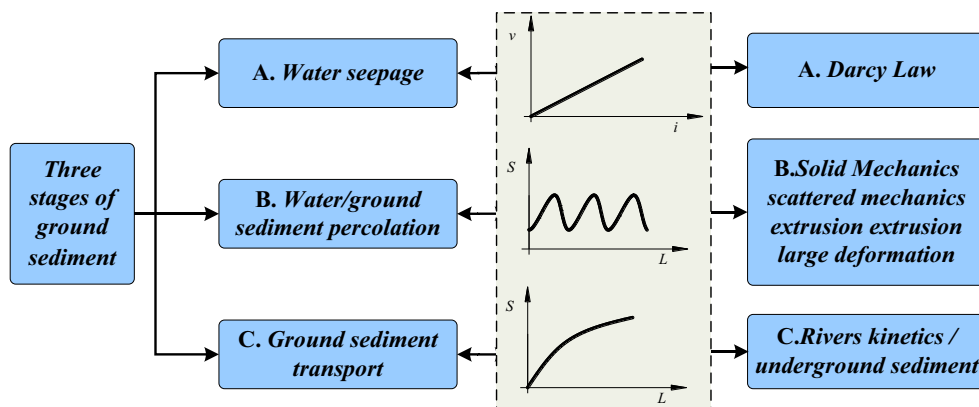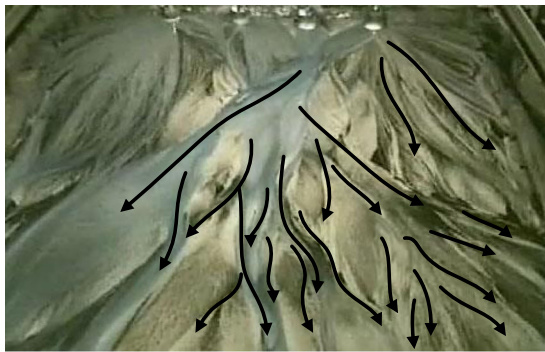
A River spread phenomenon
(Chris Paola)
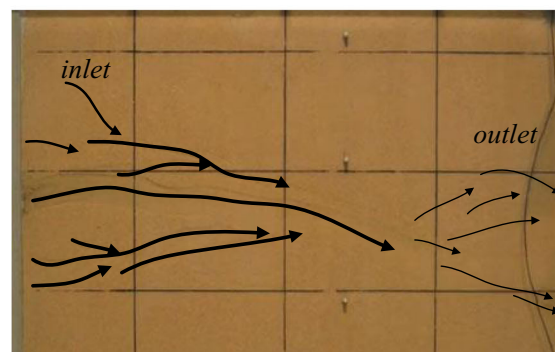
B underground channel Dumbbell
phenomenon (experiment at Deltares, Delft)

Fig. 5 River spread phenomenon and ground sediment dumbbell phenomenon

The transport is even in the early stage of the ground sediment transport. But with time going on, the non-uniform transport firstly appears at the outlet, and the new outlet channels are scattering (PSUDianaC 2011-03-11), as shown in Fig. 5b. At the outlet, the soil strength is weakened due to the water penetration (Sun & Wang 2010), while the scattering collapse appears at the outlet without any lateral support (PSUDianaC 2011–03-11).

The entrance is uniform, while the outlet randomly appears. When the outlet has some small destroyed exports (Chu-Agor et al. 2009), the channel to the outlet can become the main channel, so the sediment aggregation phenomenon appears at the entrance. Plenty of water and sediment aggregate into the main channel, resulting in an increase of the speed and flow of water and sediment, while a decrease in other places. And this process leads to further damages, as shown in Fig. 5b, in which the aggregation phenomenon can be found at the entrance.

Scattering collapse at the outlet and clustering effect on the entrance, form a dumbbell-shaped ground sediment transport phenomena, which can be called dumbbell-shaped mode of the ground sediment transport.

There are many similarities and differences between the dumbbell-shaped ground sediment transport and the river channel diffusion of the sediment transport, because the pressure of water and sediment dissipates. In this study, observations are the mainly research methods. This physical phenomenon needs to be studied and especially quantified, which has a greatly theoretical value.

paper. The river channel sediment and land sediment belong to the surface sediment, while the ground sediment exists under the surface and is in soils. The existing research in the sediment field is extended. The research direction of the sediment transport in unsaturated soils and progressive transport is pointed out. And the damage and recovery in soils due to the multi-amplitude sediment transport is explained by the mechanism. Several ground sediment physical phenomena are given, such as the ground sediment fluctuation and fluctuating transport. The fluctuating transport is divided into multi-amplitude sediment transport and single-amplitude transport, and the single-amplitude transport is the special case of the multi-amplitude transport. The dumbbell-shaped mode of the ground sediment transport is proposed, which is different from the river channel diffusion mode of the sediment transport, and is explained by the mechanism.

The research on the ground sediment is still in its infancy, the current main task is to establish and plan a more comprehensive study framework for the physical phenomena of the ground sediment. The ground sediment transport equation and boundary conditions for numerical calculations should be established. The physical laboratory equipments should be invented, and field observations and measurement should be made in the future. In this way, the research direction can be used to solve the practical problems in hydraulic engineering, transportation, energy exploitation, and so on.

Conclusions

Three different levels of the sediment are given in the paper, which are the river channel sediment, the land sediment, and the ground sediment. The ground sediment is proposed in the

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