Soilbag Structures

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The effectiveness of soilbags: mechanisms of soilbags

Soilbags, "Donow" in Japanese, are commonly used for embankment rising at times of inundation and as temporary structures during reconstruction after disasters. Soilbags had hardly been applied to earth reinforcement because of the deterioration of bags after long exposure to sunlight, especially the polyethylene bags that are extremely vulnerable to ultraviolet rays. Nevertheless, let's see the advantages of using quality-controlled soilbags (wrapping soils in a particular bag that is specified with the material and texture of the bag, the material filled into the bag and the size of the bag. The deformation coefficient of soilbags is measured by the dynamic platen loading tests) as earth reinforcement (Figure 1). This is because, when a soilbag undergoes external force or building load, tensile force occurs along the bag that in turn enhances the bearing capacity of the soilbag. Analogously, the external forces, including the self-weight of buildings, will strengthen the foundations reinforced by soilbags. It is interesting to see that soilbags have the ability to convert the external force, which was the 'enemies' against foundations, to the 'friends' of the foundations due to the action of tensile forces along the bags. Inspired by these unique characteristics, soilbags may be applied to soft foundation reinforcement. The bearing capacity of the foundation will be greatly improved, although a small amount of settlement still exists in the reinforced foundations. Wrapping soils in a particular bag is more effective and reliable than the commonly used horizontal sheet earth reinforcement. The advantages of the quality-controlled soilbags may be summarized as follows:

- Bags are cheap and easy to acquire.
- Soilbags have almost the same unit weight as soil foundations.
- The materials inside soilbags can be various construction wastes, such as crushed concrete, asphalt and tile wastes. Soilbags thus contribute greatly to the recycle of waste materials.
- No special construction equipment is required. Soilbags can even be constructed merely by human labor.
- Earth reinforcement by soilbags is environmentally friendly, because cement and chemical agents are avoided.
- Less noise and vibration are produced during constructions, in comparison to pile driving method that is commonly used in soft/weak foundation reinforcement.

The aforementioned advantages of soilbags have been expected through our laboratory and in situ experiments. More advantages have been demonstrated in engineering practices, including the amazing bearing capacity, the reduction of traffic-induced vibration, the prevention of frost heave and the reinforcement on waterlogged soft ground. For example, an ordinary polyethylene bag filled with crushed stones or sands (approx. 40×40×10 cm) can stand the load up to 200 – 300 kN. If the high strength polypropylene bags are used, the bearing load may be increased to 550 − 650 kN. Such high values are out of general imagination, even ten times higher than the predictions by the experienced workers.

Soils are essentially frictional materials. Wrapping frictional earth materials in a bag is indeed an innovative idea. In comparison with steel and concrete, materials used in soilbag constructions are flexible and environmental friendly. Moreover, when the weak/soft foundations are reinforced with numerous quality-controlled soilbags, the traffic-caused vibration can be considerably reduced. It may expect the reduction effect of cyclic shear caused by earthquake because the equivalent damping ratio of the assembly of soilbags h_{eq} = 0.3 is much higher than those of the concrete structures (h_{eq} = 0.05) and the steel structures (h_{eq} = 0.02). Besides, frost heave is a phenomenon that the ground soils expand in cold regions due to the frozen water, such as Hokkaido and Tohoku, the northern regions of Japan. It would lead to foundation settlements and cracking on the above buildings. The effectiveness of frost heave prevention by soilbags filled with coarse materials has been observed. In addition, even waterlogged extremely weak foundation can be reinforced by soilbags and shows no sign of settlement after the reinforcement. It should be noted that, no matter how much crushed stones are put into this kind of ground, they would sink without the wrapping using bags.

Why soilbags are effective in the aforementioned engineering practices? When soilbags are used to reinforce soft foundation, the soilbags are generally subjected to vertical forces from the upper structures. Figure 2 shows a soilbag subjected to the principal stresses σ_{1f} and σ_{3f} in a two-dimensional manner. The material inside the soilbag is assumed to be frictional granular materials. Under the actions of σ_{1f} and σ_{3f}, the bag becomes flat and a tensile force T is developed along the bag. Subsequently, T produces an additional stress on the particles inside the bag with components σ_{01} = 2T/B and σ_{03} = 2T/H, in which B and H are the width and height of the soilbag, respectively. As illustrated in Figure 2, the stresses acting on the particles are thus the combination of the external stresses and the stress caused by the tensile force T. At failure, the major principle stress σ_{1f} can be calculated by:

$$\sigma_{1f} + 2T/B = K_p\left(\sigma_{3f} + 2T/H\right) \qquad (1)$$

where $K_p = (1 + \sin\phi)/(1 - \sin\phi)$ is the lateral earth pressure ratio at passive state and ϕ is the internal friction angle of the material inside the soilbags. For cohesive-frictional materials, the following relationship exists between the major and minor principal stresses at failure:

$$\sigma_{1f} = \sigma_{3f}K_p + 2c\sqrt{K_p} \qquad (2)$$

The apparent cohesion c is thereby expressed as

$$c = \frac{T}{B\sqrt{K_p}}\left(\frac{B}{H}K_p - 1\right) \qquad (3)$$

The granular materials wrapped with bags exhibit the typical characteristics of cohesive-frictional materials. This has verified through series of biaxial compression tests on the wrapped aluminum rods (1.6 and 3 mm in diameters, 50 mm long and the ratio of the mixed assembly 3:2 by weight). Moreover, we have conducted experiments on soilbags filled with crushed stones (approx. 40 × 40 × height 10 cm) that the ultimate load of usual polyethylene soilbags ranges from 200 to 300 kN. The calculated ultimate load of 200 kN using Eq. (1) is approximately 40 times higher than the tensile strength of the bag itself (5 kN), which is greatly beyond ordinary expectation.

This value is equivalent to approximately 1/10 of the concrete strength per unit area. In addition, the investigations of the strength and deformation of soilbags under horizontal and inclined loads have already been examined.

- It makes sense to wrap discrete soil particles.
- Bearing capacity of foundation may be increased significantly (by 5 – 10 times).
- Bags are cheap and easy to acquire.
- Earth reinforcement by soilbags is environmental friendly, because cement and chemical agents are avoided.
- Less noise and vibration are produced during constructions, in comparison to pile driving method that is commonly used in soft foundation reinforcement.
- No special construction equipment is required. Soilbags can even be constructed merely by human labor.
- Soilbags have almost the same unit weight as soils.
- The materials inside soilbags can be various construction wastes, such as crushed concrete, asphalt and tile wastes. Soilbags thus contribute greatly to the recycle of waste materials.

Additional effects:

- Compressive forces of soilbags are amazingly high (200～300kN).
- Traffic-/machine-induced vibrations may be reduced effectively.
- Frost heave may be reduced if soilbags are filled with coarse granular materials.
- Waterlogged soft ground can also be reinforced by soilbags.

Figure 1: Characteristics of soilbags

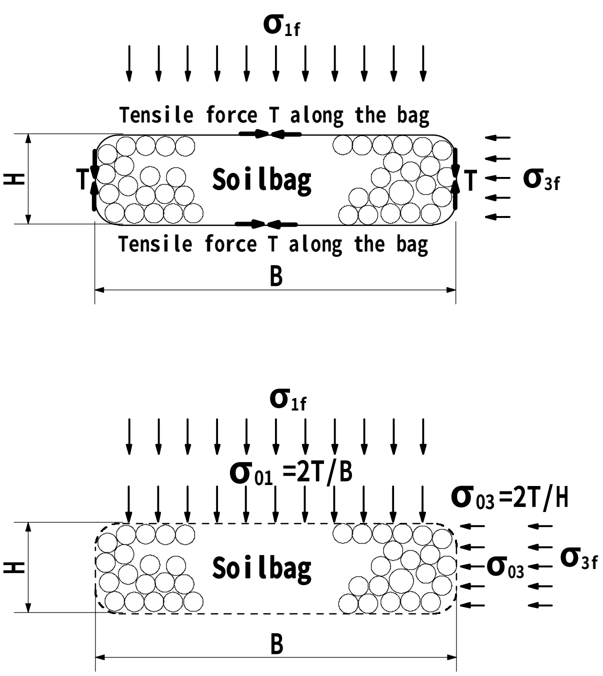

Figure 2: Force analysis on a soilbag in two-dimensional manner

Examples of Construction Using Soilbags

There have been more than 100 cases of building reinforcements using soilbags, such as piling up soilbags to construct building foundations, retaining walls, disaster restoration works on Miyake Island, restoration works of roads, and retaining walls in East Timor.

To reinforce weak/soft building foundation, the general principle is to arrange the soilbags under the footing of the building as wide (widening effect) and as deep (penetration effect) as possible so as to disperse the load from the upper building. The instruction of the arrangement of soilbags under low building foundation is given corresponding to different N-values, such as N = 1 – 2, 2 – 3 and 3 – 4. Figure 3 is an example of the reinforcement layout using soilbags for the situation of N = 1 – 2. Photo 1 shows the construction process of the foundation reinforcement for a wooden one-storey building using soilbags at YC Town, Ibaragi prefecture. The construction area is around 40×10 m. About 4500 soilbags have been used. Recycled crushed stones are used to construct soilbags (The cheapest, if possible, materials may be sought for free). The construction was completed smoothly and safely. Five years have been past after the completion, no sign of settlement or other problems has been shown. The bearing capacity of the weak foundation (N = 1 – 2) has been greatly improved. Moreover, the reduction of the traffic-induced vibration has been confirmed.

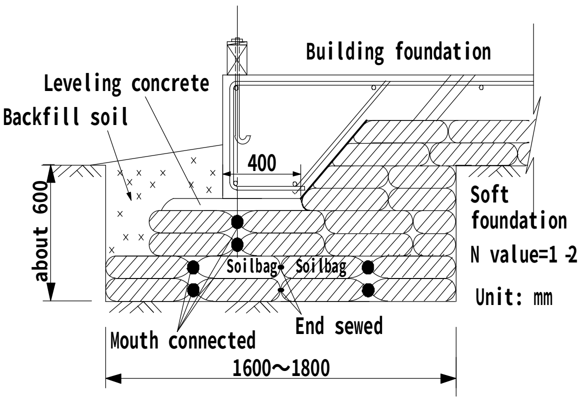

Figure 3: Layout of foundation reinforcement using soilbags.

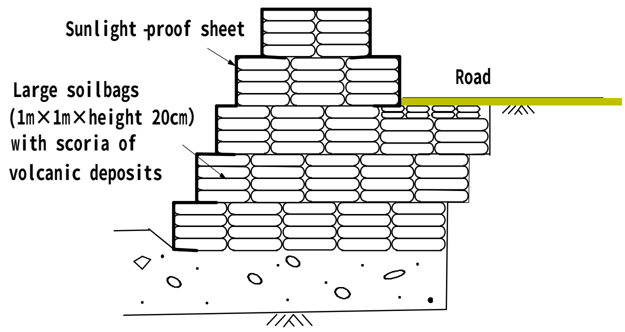

Figure 4: Typical cross-section of the debris-diversion embankment constructed with large soilbags in Miyake Island

Figure 4 and Photo-2 show the construction of a diversion channel to protect houses and main roads from the mudflows caused by the volcanic eruption occurred in Miyake Island, Japan. In the restoration works after the disaster event, approximately 10,000 large soilbags (approx. 1 × 1 × height 0.2 m) were used for the construction of the diversion embankment. With the length of 436 m and height of 2 – 5 m, the diversion embankment is used to direct the mudflows along the road by the mountain in the Tsubota district. The soilbags are filled with scoria, the volcanic debris that needs to be cleared. As shown in Figure 4, four soilbags were piled up as one unit with the height of 0.8 m, and totally five unit layers of soilbags are constructed as the banks of the diversion embankment. In order to increase the stability of the banks against external lateral forces, every unit layer of soilbags is wrapped with geogrid. A piece of sunlight-proof sheet is covered on the outside surface of the banks so as to protect soilbags against ultraviolet ray. As shown in Photo 2, it is a magnificent and lithe structure, which may effectively absorb the tremendous energy of the debris flows with its pliancy. Moreover, unlike concrete structures, the banks constructed with soilbags are easy to be removed and recovered in fields.

Photo-3 shows the construction using soilbags on the main roads in Nagoya City to reduce the traffic-induced vibration. Since the construction site is near the intersection of the main road with over 20 m in width, the traffic is heavy. As well, the bumpiness of the road surface formed by the stopping motions of vehicles was prominent. Besides, the nearby residents have been suffering from the traffic-induced vibration. In the reconstruction of this road, the cross section is illustrated in Figure 5. The soilbags were placed under the truck road with the cover of asphalt pavement. Three layers of soilbags with a total height of about 20 cm are constructed as the foundation, above which is a layer of 15 cm thick recycled crushed stone (RC-40). The crushed stone is used to protect the underlying soilbags from the high temperature of the asphalt concrete during pavement. In order to effectively reduce the traffic-induced vibration, two layers of soilbags are placed near the sidewalk. Furthermore, a layer of 27 cm thick coarse-grained asphalt concrete is constructed, following with the 10 cm thick asphalt as pavement. Before and after the reinforcement with soilbags, we measure the vibration at the sidewalk (points P1 to P3) and at the third floor of a steel-framed house (point P4). The measurements are listed in Table-1, in which the data is obtained by averaging the maximum vibration levels within 10 minutes during the measurements. It can be seen that, after the reinforcement by soilbags, the vibration levels at the four locations (points P1 – P4) are all less than 60dB that is the lowest permissible vibration level for road traffic vibration at night. In particular, the residents in the steel-framed houses satisfied after the reconstruction of the road because they hardly felt vibration. Vibration on this site will be continuously monitored.

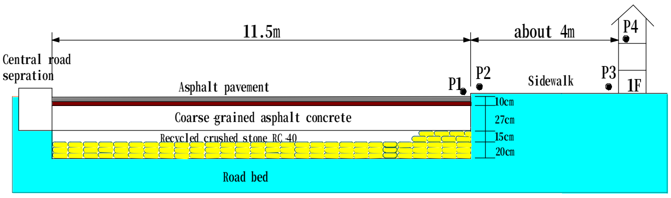

Figure 5: Cross section of the reinforced truck-road foundation with asphalt pavement and soilbags, in which P1-P4 are the observation points of vibration

Table -1 Vibration level comparisons before and after the constructions

Observation points	P1	P2	P3	P4
Before construction	67 dB	66 dB	57 dB	65 dB
After construction	55 dB	54 dB	46 dB	50 dB

Quality-controlled soilbags — from "temporary" to "permanent" material

Soilbags may be used as permanent materials instead of temporary ones through quality control to guarantee their performance. The usual bag materials for soilbags are polyethylene (PE) and polypropylene (PP), which are cheap and whose property are stable to resist acid and alkali. When soilbags are buried into ground where sunlight is shut out, they would become semi-permanent materials. Since the image of the term "soilbag" is not so attractive, the quality-controlled soilbags would be renamed as "Solpack" (Sol means soil in French), indicating that they are new and permanent construction materials. We hope this Solpack method would be widely used in earth reinforcement and civil engineering construction all over the world, including developing countries.

Photo-1: Reinforcement of soft foundation under the footing of soilbags in YC-cho, Ibaraki Prefecture, Japan.

Photo-2: Completion of the debris-diversion embankment in Miyake Island (total length 436 m)

Photo-3: Vibration reduction work using soilbags to reinforce truck-road foundation in Nagoya City