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Improvement of rural access roads in developing countries with initiative for self-reliance of communities

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Abstract

This study presents an approach to help alleviate poverty from a geotechnical engineering viewpoint. In order to improve accessibility of rural access roads to communities in rural areas of developing countries, a method to reinforce the base course with “do-nou”, a Japanese term for soil bag, has been developed. With this method, local available resources can be mobilized and the community can be involved. The main challenges are to build the base course without the necessity for qualified base course material or compaction equipment to bear the traffic load. The applicability of the available bags in developing countries to the base course was confirmed through tensile strength tests. The effectiveness of the reinforcement of “do-nou” was evaluated through a series of full-size model driving tests. The base course, built with “do-nou” and compacted manually, was able to reduce the settlement of the surface to 33% of that built with the conventional method, just by the spreading of gravel subjected to the traffic load. The technical transfer of reinforcement with “do-nou” to communities in developing countries will make it possible for the members of the communities themselves to work on rural access roads to improve trafficability. The applicability and limitations of road repair with “do-nou” were confirmed through a review of demonstrations and practices in Kenya. Typical sections with flat terrain, sags and gentle slopes, where trafficability was lost during the rainy seasons, were found to be effectively repairable with “do-nou”. Sections with steep slopes, however, are beyond the scope of “do-nou”. From an assessment of the impact after the technical transfer in Kenya, it was found that the application of “do-nou” motivates and empowers the community to initiate its own development. This earth reinforcement technology can be applied to the skills utilized by the communities in developing countries to improve the trafficability of rural access roads by considering the conditions of rural areas. Based on this technology, an approach is proposed to promote the concept of community involvement in repairing rural access roads and to enable the members of communities to improve the conditions of the roads by themselves at a low cost.

Keywords: Full-scale driving test; Trafficability; Base course; Compaction; Rural access roads; IGC: A07; H06; K14

1. Introduction

Despite massive progress in reducing poverty in several parts of the world over the past couple of decades, notably in East Asia, there are still about 1.4 billion people living at a subsistence level with less than US $1.25 per day; this constitutes 22% of the population in developing countries. At least 70% of them are living in rural areas (International Fund for Agricultural Development, 2010.). The lack of accessibility

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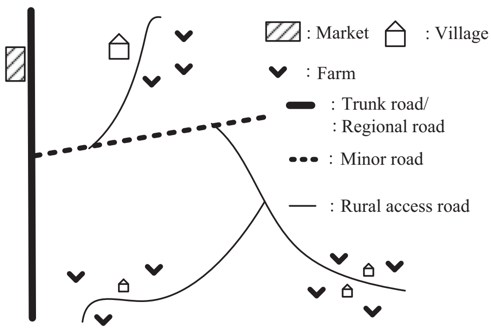


Fig. 1. Pattern diagram of road network in rural area.

Photo 1. Farmers in Kenya transporting their products on rural access roads.

to rural roads has been identified as one of the main causes of poverty among rural people (Lebo and Schelling, 2001a).

A pattern diagram of a road network in a rural area is shown in Fig. 1. Most of the rural roads and rural access roads in developing countries are unpaved, graveled or even just earth roads. During the rainy seasons, they are in such a poor condition that people struggle to pass along them by tractor, bike or even non-motorized traffic (NMT), such as bicycles or animal-drawn carts. Due to the difficulty of reaching markets to sell their agricultural produce and other goods in the rainy seasons, rural people are locked into subsistence farming. Buyers also cannot reach the village; thus, the cash crops cannot be exchanged for money and the crops rot. Better market incentives for farmers are blunted because of the physical barriers and economic costs of transporting goods to and from local markets. The impassability of the rural access roads also hampers the provision of basic social services, such as health, education and information.

The rural roads in developing countries, on which 20–200 vehicles travel per day, have been improved by governments with the financial and technical assistance of donor agencies as part of their policies for rural development. These policies have included the creation of employment opportunities, the provision of infrastructures and the fostering of agriculture (McCutcheon, 1989). Considering the lack of income opportunities in many rural areas and the intractable problems inherent in the deployment and operation of mechanical equipment for small-scattered works, labor-based technology (LBT) has been considered as the normal choice for rural road works. LBT might be defined as the economically efficient employment of as great a proportion of labor as is technically feasible, to produce as high a standard of road as demanded by the specifications and allowed by the available funding (Bjorn, 2008). Generally, these projects have targeted the rehabilitation and maintenance of rural roads or regional roads. However, the effectiveness and sustainability of past programs for rural roads has been hampered by the lack of a coherent policy framework and institutional focus on planning, funding and maintenance (Riverson et al., 2002).

Rural access roads are the lifeline for people living along the roads, and they provide intra- and near-village transport connecting the houses and farms in various communities, as shown in Fig. 1. Rural access roads are generally earth roads less than 20 km in length. Transport activities on rural access roads are performed to a certain extent on foot, sometimes by intermediate means of transport, such as bicycles and animal-drawn carts, and occasionally by motorized transport. The average daily motorized four-wheeled traffic on most rural access roads is below 50 vehicles per day (VPD), whereas the NMT can be a multiple of this number.

Rural access roads have rarely been dealt with by government projects. Due to financial constraints, cost efficiency and the small number of beneficiaries, the priority of policy makers and donor agencies to take care of these roads is low. Therefore, rural communities suffer from poor road conditions (see Photo 1). It is often argued that there is a necessity for further research on local resource mobilization and community involvement in order to maintain access between markets and rural areas (Riverson et al., 2002). However, geotechnical engineers have not yet offered solutions for improving rural access roads.

In this study, we discuss an approach for improving rural access roads with the initiative for the self-reliance of communities along these rural access roads. For this purpose, however, it is necessary to overcome the typical low availability of equipment and materials in rural areas. One of the main challenges for geotechnical engineers is to build road base course, without equipment for compaction, using qualified base course materials on the soft subgrade. These conditions do not favor or help maintain trafficability.

2. Improving rural access roads in developing countries

2.1. Road improvement with initiative for self-reliance of communities

The aim of the authors is to encourage the initiative of members of local communities by enabling them to repair the roads using simple technologies with locally available material and labor. Once the communities acquire such skills, it is expected that the problematic portions where they lose trafficability during rainy seasons can be repaired by the communities themselves. This promotes the sustainability of rural access roads, even though governments rarely intervene to improve rural roads because of a lack of funds. It is true that frequent repair works will be needed. However, if people receive proper training, they will be able to repair the roads by themselves with the available material when poor road conditions require it.

2.2. Conditions of rural access roads

Generally, rural access roads are earth roads. Trafficability is maintained during the dry season; however, in the rainy seasons, various road sections become impassable.

In order not to disperse the limited resources, and considering the low volume of traffic, efforts to improve rural access roads should be focused on the essential issues, that is, spot improvements of critical sections and surface drainage.

Conventionally, those critical portions have been fixed by the communities in ad-hoc ways using large stones with a particle size greater than 100 mm or gravel with a single range of grain-size distribution (Fig. 2(a) and (b)). However, the effectiveness does not last, because the particles are ground down into the subgrade due to the load of the traffic.

2.3. Spot improvements using "do-nou"

The authors propose the use of "do-nou", the Japanese term for soil bag, as one of the most appropriate technologies for improving rural access roads, as shown in Fig. 2(c). At the critical sections, "do-nou" form the base course that bears the traffic load. It is found that soil wrapped in bags in an orderly manner has a high bearing capacity that can be predicted using theoretically derived equations (Matsuoka and Liu, 2006).

The advantages of using "do-nou" for spot improvements are summarized as follows:

(1) The bags used for crops, fertilizer or sugar, etc., commonly found in rural areas of developing countries (Photo 2), are identified as "do-nou" bags, and comprise one of the available geosynthetics.

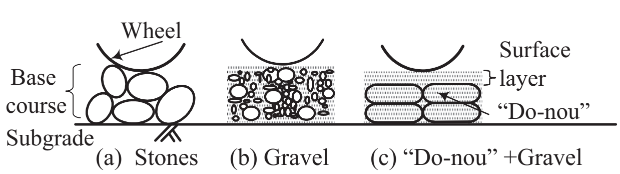


Fig. 2. Structures of base course on soft subgrade.

Photo 2. Used bags for selling at market in Kenya.

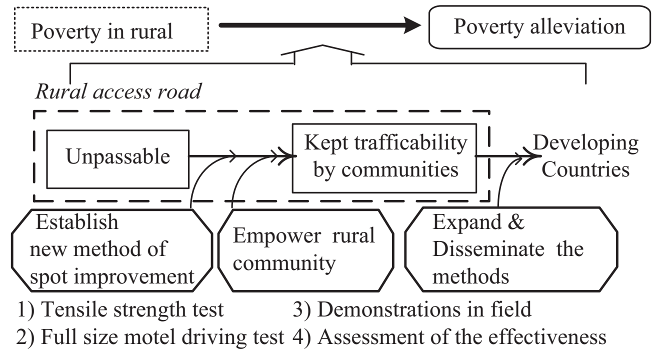


Fig. 3. Flowchart to improve rural access roads and alleviate poverty.

(2) "Do-nou", soil wrapped in bags, has a high comprehensive strength; for example, it can be applied to earth reinforcement in railway ballast and soft building foundations, as well as to retaining walls (Matsuoka and Liu, 2006).

(3) No heavy compaction equipment is necessary.

2.4. Flowchart to improve rural access roads and alleviate poverty

Fig. 3 shows a flowchart for improving rural access roads in developing countries for the purpose of helping to alleviate poverty. The first step is to establish spot improvement methodology using "do-nou" as a technically viable and effective solution. In order to determine the suitability of the available bags for "do-nou" application as the base course of rural access roads, tensile strength tests have been conducted on the sampled bags. Then, the effectiveness of the manual compaction on "do-nou" has been examined through full-scale driving tests in Japan. Moreover, the effectiveness of building a base course with "do-nou" and the mechanism of the reinforcement have been assessed.

The second step is to empower rural communities by transferring the established method. Spot improvement methodology using "do-nou" has been demonstrated by repairing rural access roads in 13 countries in Asia and Africa. The responses of the communities in these countries to the technical transfer were monitored based on whether or not the state of the roads improved by "do-nou" satisfied the communities and on how the communities were empowered by the continuous activities involved in keeping the roads passable.

Furthermore, some of the demonstration sites were assessed about 1 or 2 years after the construction date to confirm the effectiveness of "do-nou" to rural access road repairs. The results of the assessment have revealed the scope of the applications and the limitations of "do-nou".

3. Tensile strength tests on bags utilized for wrapping soil, "do-nou", in developing countries

Through an assessment of the available material for the improvement of rural access roads in developing countries, the woven bags are identified as "do-nou" bags, one kind of geosynthetics material. In order to determine the suitability of available bags for “do-nou” application to the base course of rural access roads in developing countries, the bags were sampled and then tensile strength tests were conducted. The specifications and summarized results of the tested bags are listed in Table 1.

The woven bags used for sugar, crops, fertilizer, etc., commonly found in rural areas of developing countries, are made from polypropylene, whereas the “do-nou” bags, generally used in Japan, are made from polyethylene. The latter material is comparatively cheaper, but also weaker than polypropylene. As an available bag in Kenya, the sisal bag was also found to have a great potential for use. Presumably, if sisal bags can be used as “do-nou”, the local sisal industry in some countries will be rejuvenated and empowered.

The bags that hold 20 kg, Sample C in Table 1, are similar in size to Sample A, commonly used as “do-nou” in Japan. These are the most convenient for use in repairing roads, because they are easy to transport and to lay properly in terms of weight and geometry after the bags are filled with 0.016 m^3 of soil. After being filled, the bags weigh about 20 kg. After compaction, they are approximately 40 cm in both width and length and 10 cm in thickness. Sample B, bags that hold 100 kg of maize, are too large. They would be too heavy to carry or to use when manually constructing a base course. However, they could be used if they were modified to a size similar to that of Sample A by cutting them down and sewing up the open side.

Tensile strength tests were conducted on those sampled bags that were 100-mm long (excluding the end support length) and 50-mm wide with a strain rate equal to 1%/min. Fig. 4 shows the tensile stress–strain curves obtained. The maximum stress was taken to be the tensile strength of the respective bags. Due to the material, Sample A had the lowest tensile strength, 6.6 kN/m, among all the tested bags. When comparing the tensile strength of Sample B to that of Sample C, it can be said that as the number of strings per 2.54 cm (1 in.) increases, the tensile strength of the bags increases. Although sisal bags show less ductility than polypropylene or polyethylene bags, they have the high tensile strength of 11.2 kN/m. However, they cost seven times more than polypropylene bags. Therefore, it is not cost effective to use them in “do-nou” application.

Tensile strength (T) is one of the parameters used to identify the bearing capacity (σ_{1f}) of soil wrapped in bags, which can be obtained according to Eq. (1) assuming that the soil put inside the bags is at failure due to unconfined compression (Matsuoka and Liu, 2006).

$$\sigma_{1f} = (2T/B)\{(B/H) \times K_p - 1\} \tag{1}$$

where, B = width of the “do-nou”, H = height of the “do-nou” and $K_p = (1 + \sin\varphi)/(1 - \sin\varphi)$ is the lateral earth pressure ratio at the passive state.

Soil (0.016 m^3) with an internal friction angle $\varphi = 30^\circ$, which is a low figure among natural granular soils, is wrapped in Samples A, B and C bags. Once filled, the bags are 0.40 m in both width and length and 0.10 m in thickness. The bearing capacities of the soil wrapped in those bags are calculated using Eq. (1) as 363.0, 616.0 and 770.0 kPa. When the bags filled with soil are applied to build base course, they are subjected to tire contact pressure from traffic, which is generally considered equal to the tire inflation pressure (Giroud and Han, 2004). The tire inflation pressure in this study varied depending on the type of vehicle, e.g., about 500 kPa for 2-ton trucks and about 700 kPa for 4-ton trucks. It can be said that Samples B and C both have sufficient tensile strength to withstand the typical traffic load of 2-ton trucks on rural access roads.

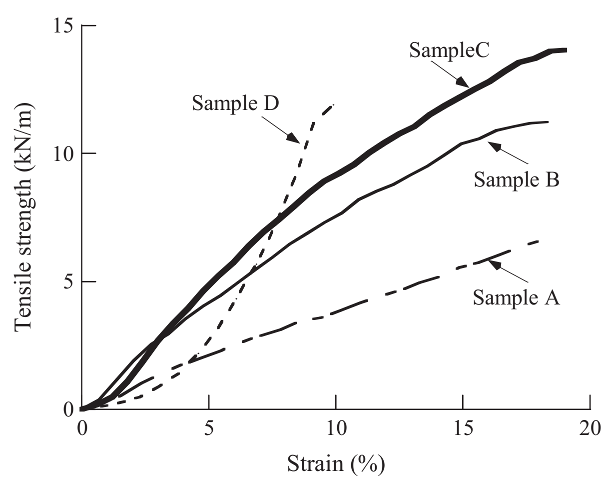


Fig. 4. Stress–strain curves of bags.

Table 1
Specifications of bags subjected to tensile strength tests.

	Unit	A	B	C	D
Name		Do-nou	Bag for maize	Bag for sugar	Bag for coffee
Material		Polyethylene	Polypropylene	Polypropylene	Sisal
Production area		China	Kenya	Papua New Guinea	Kenya
Size of bag	cm	60 × 48	112 × 72	63 × 46	94 × 66
Weight	g per bag	46.0	150.0	52.2	836.0
Unit weight	g/m^2	79.9	93.0	90.8	674.2
Number of strings per 2.54 cm width	/2.54 cm (per inch)	9	10	13	6
Tensile strength	kN/m	6.6	11.2	14.0	11.9
Strain at yield	%	18.0	18.3	19.0	9.9

Based on the above, the following can be set as criteria for the use of available bags in rural areas of developing countries as "do-nou":

(1) Empirically, it can be said that the available bags, used for crops or fertilizer, etc. in developing countries, are woven with polypropylene strings, not polyethylene.
(2) The size of bags for 20-kg contents is suitable in terms of tensile strength, dimension and mass. Alternatively, the bags for 90- or 100-kg contents can be used after modification to resemble the 20-kg bags. It is important to control the size of the bags of soil and to make them uniform from the aspect of construction performance.
(3) When the number of woven strings of polypropylene per 2.54 cm of width is more than or equal to 10, the bags are said to have sufficient tensile strength to withstand the load of 2-ton trucks on typical rural access roads.

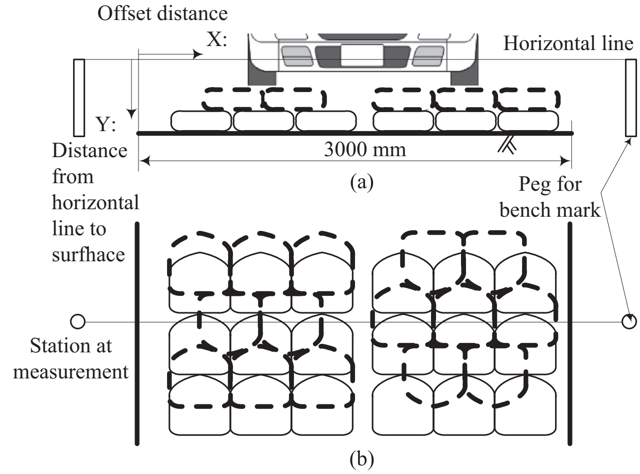


Fig. 5. Cross- and plain section views of full-size driving tests.

4. Full-size model driving tests

4.1. Test objectives

The objectives of the full-size model driving tests were as follows:

(1) To evaluate the trafficability of the base course built with "do-nou" filled with three different kinds of materials.
(2) To confirm the effectiveness of manual compaction compared with machinery compaction, such as by a plate compactor.
(3) To demonstrate the effectiveness of the reinforcement of the base course built with "do-nou" (Fig. 2(c)) compared to the conventional methods, by simply placing the gravel as shown in Fig. 2(b).
(4) To examine the mechanism of the reinforcement of the base course built with "do-nou".

4.2. Experimental overview

The full-size model driving tests were performed in the Ujigawa Open Laboratory of the Disaster Prevention Research Institute at Kyoto University in Japan. In these tests, two layers of "do-nou" were laid as the base course in the test field and a vehicle was actually made to pass over the base course built with "do-nou". The test field was 3 m in width and 5 m in length. A cross-section view of the full-size model driving tests is shown in Fig. 5 and Photo 3. The tire installation pressure of the test vehicle was 220 kPa. All passes were made at a speed less than 10 km/h, driving forward and in reverse along a channelized wheel path.

The response of the test sections to vehicle loading was evaluated from measurements of the cross-sectional profile of the base course surface and, in some cases, the subgrade surface with the cumulative number of vehicle passes. The settlement of the surface after the vehicle had passed over a certain number of times was measured as the difference between the distance from a horizontal line set on the bench marks, installed on both sides of the test field, to the surface and that before the vehicle had passed over.

Photo 3. Overall situation regarding full-size model driving test.

4.3. Materials and experimental conditions

The three test series were performed as shown in Table 2. The parameters set for these tests were (1) the cone index of the subgrade obtained through in situ portable cone penetration tests, (2) the material put inside the bags, (3) the compaction method and (4) the structures of the base course.

In all cases, the bags made from polyethylene with specifications similar to those of sample A in Table 1 were used as "do-nou". This was because the tire inflation pressure of the test vehicle was so small that the bags made from polyethylene were able to bear the tire contact pressure. The bags made from polyethylene and polypropylene showed very similar workability and tensile ductility as were found from the tensile strength tests. Therefore, the performance of the reinforced base course with "do-nou" can be examined through the test series conducted with "do-nou" made from polyethylene. In order to maintain uniformity in size of the "do-nou" filled with different types of soil, the same method for filling up the bags with soil was applied. Considering the

Table 2
Cases of full-size model driving tests performed.

Series	Case	Cone index of subgrade	Material put inside bags	Water content (%)	Compaction method	Structure of base course
I	1	435.0 kN/m^2	Crushed stones	3.6	Plate compactor	Two layers of “do-nou”
	2		Gravel	4.7		
	3		Decomposed granite soil	1.0		
II	4	N/A	Gravel	4.7	Plate compactor	Two layers of “do-nou” filled with gravel
	5				Wooden mallet	
	6				Padding	
III	7	435.0 kN/m^2	Gravel	4.7	Wooden mallet	Gravel layer with width of 5 cm + two layers of “do-nou” filled with gravel
	8					Gravel layer with width of 25 cm

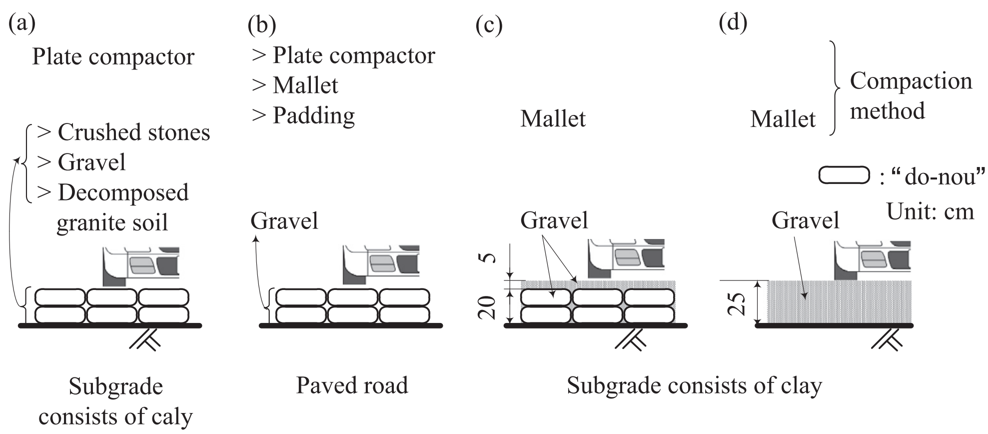


Fig. 6. Half cross-sections of all cases of full-size model driving tests. (a) Case 1-3, (b) Case 4-6, (c) Case 7 and (d) Case 8.

practicability of filling the bags with soil in rural areas of developing countries, the following method was chosen. The volume of soil to be put into the bags was measured with a calibrated container of 0.016 m^3; then, the open end of the bag was filled with soil, held firmly by hand and tied at the position over the fist, approximately 10 cm from the bottom of the fist. After the “do-nou” were compacted, the width and the length of the bags were both 40 cm and the thickness was 10 cm.

In Series I and II, the driving tests were conducted at the test field whose subgrade soil consisted of clay with a thickness of 500 mm. The liquid limit of the clay was 75.0% and the plastic limit was 25.0%. The water content of the clay measured just before the driving tests ranged between 40.0% and 42.0%. To estimate the trafficability of the subgrade, portable cone penetration tests were carried out. The average cone index at depths of 5 and 10 cm was 435.0 kN/m^2. According to the Japan Road Association (2003), a cone index greater than 1200 kN/m^2 is required to maintain the trafficability of trucks with a tire contact pressure of 350–500 kPa.

In Series I, the three kinds of material were put inside the bags, namely, crushed stones (Case-1), gravel taken from a river (Case-2) and decomposed granite soil (Case-3). Two layers of “do-nou”, filled with each soil, were laid at the wheel path on the soft subgrade forming the base course, as shown in Fig. 6(a). Each layer of “do-nou” was subjected to 4 passes of the plate compactor for compaction. The grain-size distribution

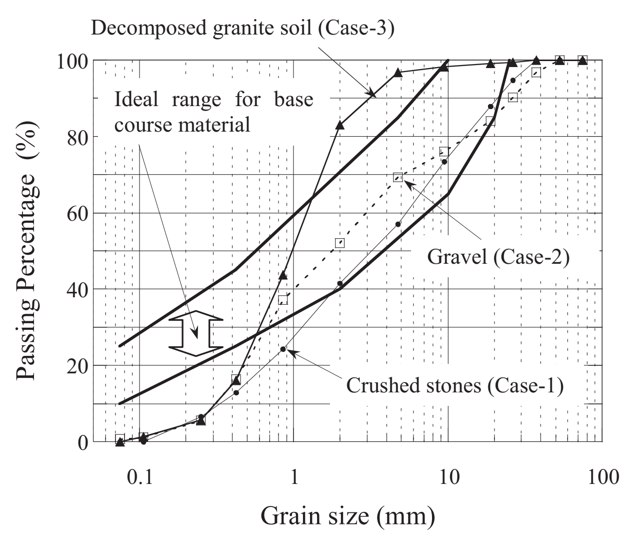


Fig. 7. Grain-size distribution curves of material put inside bags.

curves for those materials are shown in Fig. 7 together with the ideal range for the base course material. The crushed stones are a qualified material for use in base course produced on query to modify according to the requirement, whereas the gravel, which has a similar grain-size distribution to the crushed stones, is collected from a natural resource. The decomposed granite soil is sandy. The water content of the crushed stones, gravel and decomposed granite soil put inside the bags were 3.6%, 4.7% and 1.0%, respectively. Considering the working period during the dry season and the impracticability of trying to control the soil moisture in rural areas of developing countries, the state of all the soil put inside the bags was drier than that at the optimum moisture content. We studied the rut development for these three types of materials brought about by the vehicle passes.

For Series II, two layers of "do-nou" filled with gravel were laid on the paved road where the settlement caused by the vehicle passes would be negligible. Then, each layer was compacted in the following manner. The "do-nou" were subjected to four passes with a plate compactor (Case-4), 10 blows with a wooden mallet (Case-5) and padding (Case-6). The objective of Series II was to examine whether the manual compaction of "do-nou" could be equivalent to compaction with a plate compactor.

In Series III, two types of structures of base course were built on the subgrade. The first (Case-7) consisted of a gravel layer, whose width was 5 cm, and two layers of "do-nou" filled with gravel. The second (Case-8) consisted of only a gravel layer, whose width was 25 cm, and whose total thickness was the same as that of the base course in Case-7. In order to simulate the conditions in rural areas of developing countries, the compaction was conducted manually by a wooden mallet in both cases. In Case-7, the "do-nou" and the gravel layer were compacted by a wooden mallet, whereas in Case-8, the gravel was placed in 3 layers of 100, 200 and 250 mm with each layer being compacted by a wooden mallet. In both cases, just before the passing of the test vehicle, the surface was sprinkled with water for 30 min to simulate a precipitation rate of 40 mm/h.

4.4. Experimental results and discussion

Fig. 8 shows the settlement of the surface of base course built with "do-nou" and subgrade for Series I (Cases-1–3) after 20 passes of the vehicle. Since the base course of "do-nou" contained lumps of soil, the surface settlement was affected by the lack of continuity near the edges of the "do-nou" (see Photo 3).

Heave occurred adjacent to the channelized wheel path where the "do-nou" bags were laid; however, it was localized and caused no significant settlement of the surface of the base course at the longitudinal centerline or on either side. The greatest heave was observed in Case-3, followed by Case-2 and the smallest in Case-1.

Rut depth is defined as the distance between the highest point adjacent to the channelized wheel path and the lowest point in the rut beneath a wheel. The variation in rut depth with a cumulative number of passes is illustrated for each base course under Series I in Fig. 9. In Case-3, after 25 passes, the rut that formed was 150 mm deep. This prevented the vehicle from being driven more on the test field, because the bottom of the vehicle collided with the base course. It can be said in this paper that the 150-mm rut depth is defined as trafficability failure. In Case-2, after 80 passes, the rut became so deep that it was impossible to drive over it. On the other hand, in Case-1, the rut depth was 80 mm after 200 vehicle passes. Clearly, trafficability was maintained.

In order to improve the trafficability on subgrade with clay, we found that building the base course with "do-nou" filled with the crushed stones was the most effective choice. However, it is difficult for rural communities in developing countries to procure crushed stones adjusted to the optimum grain-size distribution, because crushed stones are more expensive than gravel just taken from a quarry. In the context of this study, gravel is considered to be one of the most appropriate materials for road improvement activities that can be performed by trained people from the local communities (the concept of self-reliance).

Fig. 10 shows the relationships between the deformation of "do-nou", just beneath the wheel where the deepest settlement exists, and the number of vehicle passes for Cases-4–6, Series II. The deformation at the edges and the center of "do-nou" compacted in three different ways are compared. In all cases, the deformation of "do-nou" increased as the number of vehicle passes increased until the number of passes reached 30. Then, the deformation showed convergent behavior until the end of the driving test. The convergent deformation of "do-nou" at the edge and the center of the "do-nou", compacted by the plate compactor, is 5.0%; this is equivalent to that at the

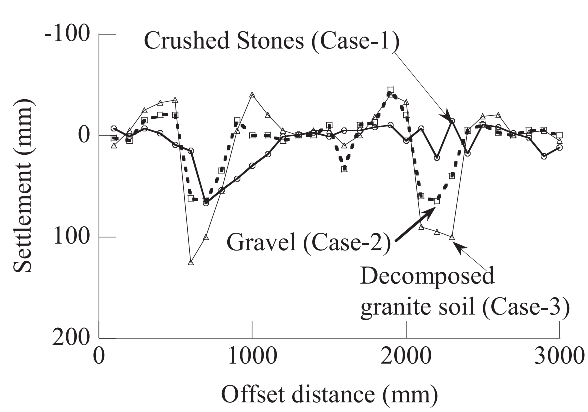


Fig. 8. Settlement of surface of base course after 20 passes.

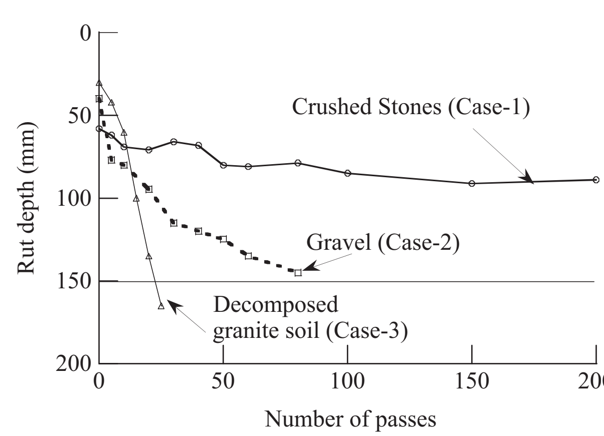


Fig. 9. Relationship between rut depth and number of passes.

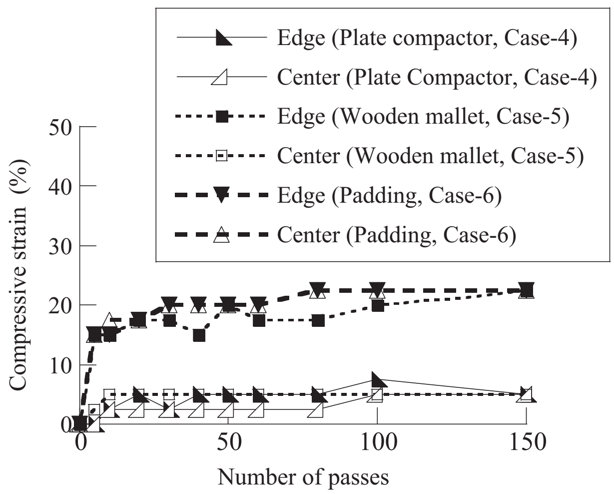


Fig. 10. Relationship between deformation and number of passes.

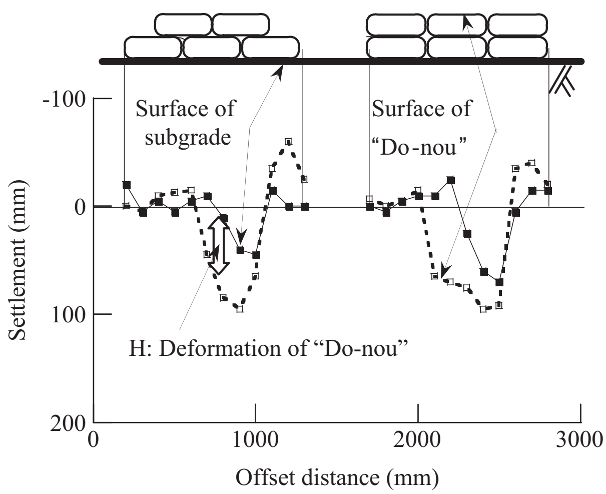


Fig. 11. Settlement of surface of "do-nou" and subgrade after 80 passes.

center of the "do-nou" compacted by the wooden mallet. The deformation at the edges of the "do-nou", compacted by the wooden mallet, and at both the edges and the center of the "do-nou", compacted by padding, however, are 22.5%.

Therefore, it can be said that in order to compact "do-nou" as efficiently as can be done with a plate compactor, although compaction by a wooden mallet is sufficient, careful compaction at the edges of "do-nou" is required.

The effect of the conditions of the subgrade on the deformations of "do-nou" was examined by comparing the deformations of "do-nou" between Cases 2 and 4. The settlement of the surface of "do-nou" and the subgrade after 80 passes in Case-2 is shown in Fig. 11. In Case-2, the settlement of the surface of the subgrade was measured after removing "do-nou" just after the end of 80 vehicle passes, when the rut that developed was so deep that there could be no further passing of the vehicle. The offset distance with the deepest settlement between the "do-nou" and the subgrade do not correspond. This is attributed to the horizontal displacement of the "do-nou" caused by vehicle passes and the gaps between "do-nou" and adjacent "do-nou". However, the deformations of the "do-nou" in Case-2 are assumed to have been obtained through knowledge of the differences in settlement between the surfaces of "do-nou" and the subgrade, which is shown as H in Fig. 11. Fig. 12 shows the deformations of "do-nou", laid on the subgrade consisting of clay (Case-2) and laid on the paved road after 80 passes of the vehicle (Case-4). The settlement of the subgrade causes the larger deformation of the base course built with "do-nou". Additional measures to prevent deformation of the subgrade, such as laying geosynthetics on the subgrade to distribute the traffic loads and to reduce the maximum vertical stress on the subgrade, would contribute to the improvement of trafficability by building a base course with "do-nou". It should be noted in studies on the stabilization of unpaved roads with geosynthetics (e.g., Fannin and Sigurdsson, 1996), that it is assumed that the base course material is qualified, that compaction is controlled by compacting equipment and that the water content is adjusted to the optimum moisture content. This study has taken the challenge to reinforce the base course without the use of qualified material or equipment for compaction and without adjusting the water content, while encouraging communities to work on the roads, and thus, improve trafficability.

The response of the road, improved in two ways, Cases-7 and 8, to vehicle loads after 10 passes, is shown in Fig. 13

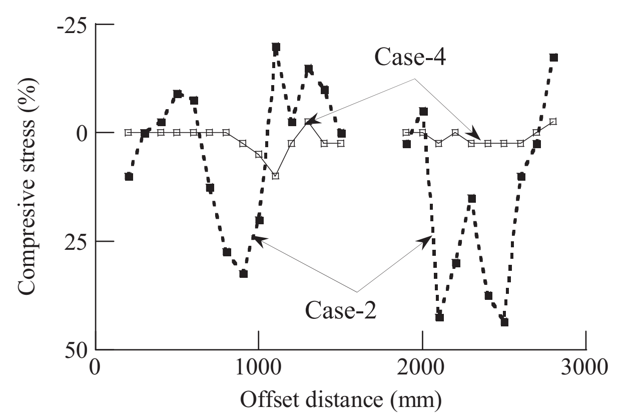


Fig. 12. Deformation of "do-nou" in Case-2 for clay subgrade and Case-4 for paved road.

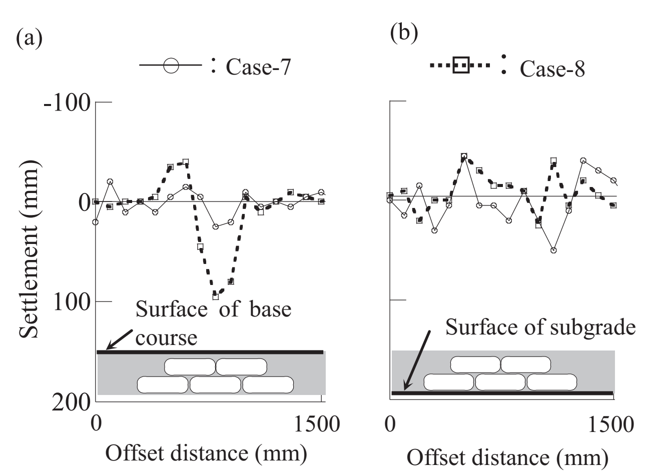


Fig. 13. Settlement of surface of (a) base course and (b) subgrade in Cases-7 and 8 after 10 passes.

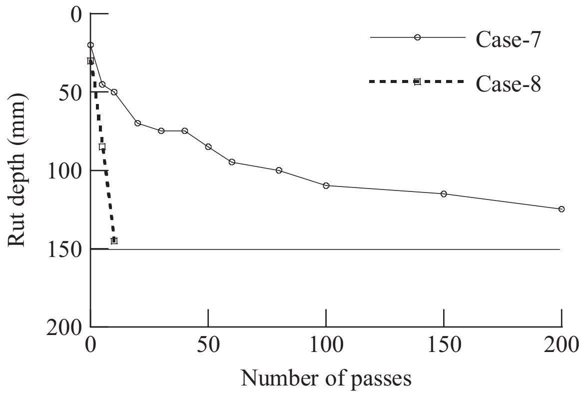


Fig. 14. Relationship between rut depth and number of passes.

together with the settlement of the surface of subgrade. Only half sections are shown because of the symmetry of the settlement. After 10 passes of the vehicle, in Case-8, the vehicle could not pass the test field any further because of the deep rut that had developed. The settlements of the surface of the subgrade were measured from dug trenches and the removal of the "do-nou" extended over only half the width of the road. In Case-7, under the assumption that there were no significant disturbances as a result of these activities for observation, the trafficking was continued until 200 passes. The relationship between the rut depth at the other wheel side, where the base course and the "do-nou" were not removed after 10 passes, and the number of passes, is shown in Fig. 14. In Case-7, even after 200 passes, road trafficability was maintained.

The rut depth after 10 passes in Case-7 is 33% of that in Case-8 (Fig. 13(a) and Fig. 14), whereas there is no significant difference in the settlement of the subgrade between Cases-7 and 8 (Fig. 13(b)). It is found that "do-nou" is used to reduce the compression of the layer of base course subjected to the traffic load. This phenomenon proves that "do-nou" bags contribute to preventing the lateral movement of the base course material and to increasing the stiffness of the base course material. From the observation of the subgrade, it is obvious that the use of "do-nou" prevents the loss of base course material into soft subgrade soil. However, the effect of the distribution of traffic loads and the reduction of the maximum vertical stress on the subgrade, as well as the increase in the bearing capacity of the subgrade, which are typically expected as the influence of the geosynthetics placed at the interface between base course and subgrade (Giroud and Han, 2004), are not found. This is because trafficability failure occurred after just 10 passes in Case-8. If it had been possible to compare the settlement between Cases-7 and 8 after several passes, the above-mentioned influence could have been observed.

5. Applications of road improvement using "do-nou" in Kenya

The objective of this study is to improve the accessibility on rural access roads in developing countries. The strategy for achieving this objective is to enable the members of communities living along the rural access roads to repair the problematic portions effectively by themselves using locally available material. As a specific method, the road improvement method using "do-nou" has been experimentally determined. To assess the effectiveness of the method using "do-nou", demonstrations and practices of road repair with "do-nou" by communities in Kenya are reviewed. The authors′ group has conducted demonstrations of road repair with "do-nou" to communities in 13 developing countries in Asia and Africa as of July 2012. In this paper, however, only the cases in Kenya, where the authors′ group has stationed and monitored the conditions of the sections maintained using "do-nou", are discussed.

5.1. Response of the communities in Kenya to road improvement works using "do-nou"

In Kenya, a total of about 10 km of rural access roads was improved using "do-nou" in 60 communities since 2007. The typical procedures of the demonstrations were as follows. Firstly, the drainage system was improved, and then muddy parts where trafficability failures had been occurring were replaced with "do-nou" filled with locally available granular soil. For problematic portions with deeper ruts or overly soft ground, the required number of "do-nou" layers was adjusted accordingly, sometimes exceeding two layers.

At first, the people in these rural areas could not believe that the rural access roads could be improved by using "do-nou" bags and labor, but no equipment. Therefore, at the beginning of the demonstration period, only a few people participated. As they realized the firmness of "do-nou" after the manual compaction (Photo 4) and that the problematic portions had improved after the application of "do-nou", the road users realized the effectiveness of the method and started to feel interested in the activities (Photo 5). According to the record of the number of participants at a demonstration site, the number of participants increased, as shown in Fig. 15. As an example case, the road conditions before and after the improvement works are shown in Photos 6 and 7, respectively. The data of the quantity survey for the demonstration presented in Photo 7

Photo 4. Participants feeling firmness of "do-nou" after compaction during demonstration in Kenya.

Photo 5. Communities compacting “do-nou” for road maintenance in Kenya.

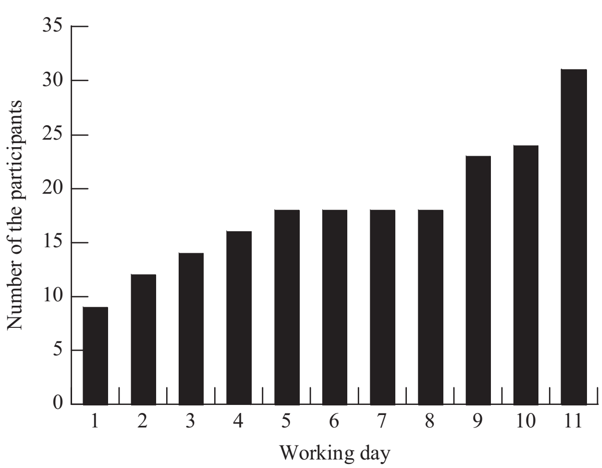


Fig. 15. Number of participants during demonstration in Kenya.

Photo 6. Road condition before maintenance at demonstration site in Kenya.

is summarized in Table 3, where it is shown that the cost per meter is US $ 6.71 and that the productivity per day with 20 people was 30 m.

Photo 7. Road conditions at same place shown in Photo 6 after maintenance in Kenya.

Table 3
Data of quantity survey for road improvement using “do-nou”.

Item	Unit price (US$)	Quantity	Cost in total (US$)	%
Do-nou bags	0.16/bag	350 bags	56.0	28.0
Granular soil	2.8/ton	28.0 ton	78.4	39.0
Truck	14.5/trip	4 trips	58.0	29.0
Tool			9.0	4.0
Total			201.4	100

From the review of the demonstration cases, it can be said that one of the main challenges is to train people living in rural areas to implement road maintenance procedures properly by themselves and to realize the full potential of this “do-nou” method. The practical aspects of the method in the circumstances of rural areas of developing countries should be maintained to keep a certain volume of soil inside the bags, to keep the same position at the open end of “do-nou” to be tied and to compact properly. Moreover, the effectiveness was immediately proven and it enabled the participants to adopt the new method.

5.2. Applicability and limitation of “do-nou” to the several conditions of rural access roads

In the project areas of Kenya, the following sections of rural access roads, where trafficability was typically lost, were maintained effectively by applying “do-nou”; muddy and rutty sections at sags (Photos 6 and 7), deep ruts in flat portions and gullies in gentle slopes (Fukubayashi and Kimura, 2011a). The typical cross-section to maintain the flat portions is shown in Fig. 16. In all cases, first of all, the drainage system needed to be maintained. Then, the soft base course was reinforced with “do-nou” filled with locally available granular material.

On the other hand, “do-nou” was not applicable to maintain sections with steep slopes, where the top layer consisted of granular material that would soon be washed away because of the runoff water resulting in the exposure of the “do-nou”. Once “do-nou” bags were exposed to ultra violet or direct friction from the tires of passing vehicles on the road, the bags

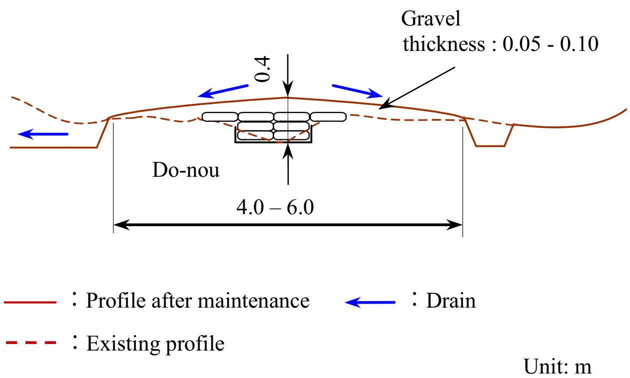


Fig. 16. Cross-section of maintained road at flat portion.

Photo 8. Exposed "do-nou" at slope.

Photo 9. Log bridge constructed after demonstration of "do-nou".

were easily torn, as shown in Photo 8, and the reinforcement effect was reduced considerably.

The duration of the effectiveness of the road improvement using "do-nou" is sometimes argued. However, because of the concept of the road improvement using "do-nou", the target durations for the effectiveness of road improvement using "do-nou" is from 1 to 3 years. Continuous maintenance works by the communities, with the locally available material, would extend the roads′ sustainable trafficability.

5.3. Impact of the road improvement using "do-nou"

In a certain village in Kenya, after receiving training on road improvement with "do-nou", the farmers went ahead and constructed a bridge across a river by themselves using logs and "do-nou" (Photo 9). The villagers′ lives have changed since then, because the volume of crops they can transport to the market has increased, as well as the number of buyers′ vehicles.

5.4. Proposal of an approach to improve the trafficability of rural access roads

The goal of this approach is to promote the concept of community involvement in improving rural access roads and to enable members of communities to improve the road conditions by themselves at a low cost, namely, from US $5 to 10 per meter. The farm-to-market transport chain is shown in Fig. 17 (edited by authors, Lebo and Schelling, 2001b) together with other measures for repairing road networks. Rural access roads that connect farms to market centers should be improved with basic, simple and effective measures, such as vegetation control, clearing drainage and spot improvement using "do-nou". It is true that occasionally, the conditions of rural access roads are not maintainable and rehabilitation work is required; however, it is important to improve the current conditions to the maximum extent possible and with limited resources.

On the other hand, governments should take responsibility and sometimes play a role, independently or with the assistance of donor agencies, to maintain rural roads. If the rural roads are not maintainable, then the rehabilitation projects, which cost from US $20 to 40 per meter, according to the records of the LBT projects in East Timore, should be conducted. The rehabilitation works comprehensively comprise vegetation control, ditching, camber formation, drainage work inclusive of concrete structure and graveling. Spot improvement using "do-nou" and other applications of "do-nou" for retaining walls, etc., are also included in the rehabilitation or maintenance projects.

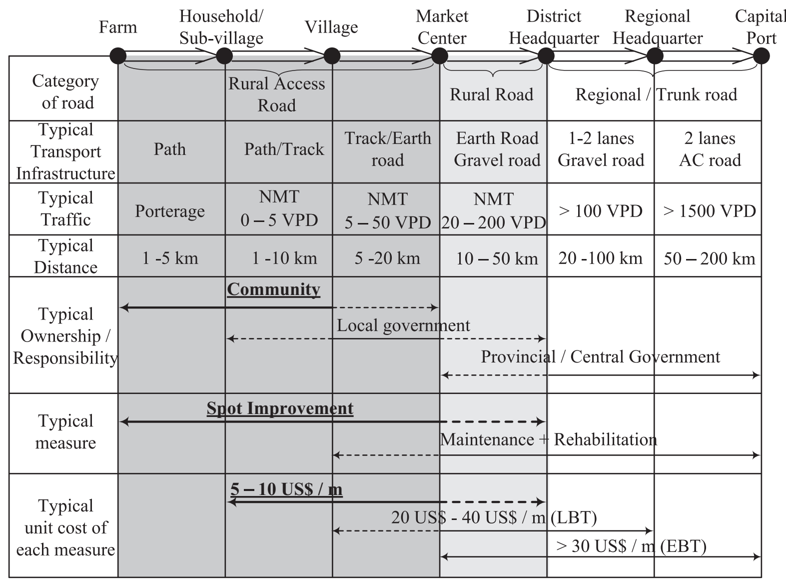
5.5. Dissemination of road improvement using "do-nou" in developing countries

Road improvements using "do-nou" have been disseminated to communities in rural areas of developing countries through several approaches, such as technical cooperation projects for rural development aimed at marketing agricultural crops, community development projects implemented by local universities, studies to promote the Base of Economic Pyramid (BOP) Business perspectives and Japanese volunteers dispatched to a number of developing countries (Fukubayashi and Kimura, 2011b).

6. Conclusion

Efforts to alleviate poverty were the motivation for developing an approach to improve rural access roads. The earth reinforcement method of "do-nou" was applied to building road base courses considering the circumstances of rural areas in developing countries. The main conclusions of this study are as follows:

(1) Woven bags for crops and fertilizer, etc., which are available in rural areas of developing countries, have



AC:Asphalt concrete: NMT:Non motorized transportation: VPD:Vehicle per day: LBT:Labour based technology: EBT: Equipment based technology.

Fig. 17. Farms-to-market transport chain. (edited by authors, Lebo and Schelling, 2001b)

enough tensile strength to be used for building the base course of rural access roads.

(2) The size of bags for 20-kg contents is suitable because they are easily carried after being filled with soil. When the number of woven strings of polypropylene per 2.54 cm width is equal to or more than 10, it can be said that the bags have the necessary tensile strength to withstand the traffic load of 2-ton trucks.

(3) The efficiency of gravel as base course material put inside bags, which are simply collected from quarries, not processed to be qualified material, was examined.

(4) The manual compaction at the center of “do-nou” is equivalent to compaction with a plate compactor. However, special care is required when manually compacting the edges of “do-nou”. It is a considerable advantage for soil to be wrapped in bags so that the soil can be compacted equivalently by manual effort to that by equipment.

(5) The rut depth of the base course reinforced with “do-nou” was reduced to 33% of that without “do-nou” at 10 vehicle passes. The base course with “do-nou” maintained trafficability after 200 vehicle passes, whereas trafficability failure occurred at 10 passes on the base course without “do-nou”.

(6) “Do-nou” can increase the stiffness of base course material to bear the traffic load by requiring only locally available materials and manual compaction.

(7) The practicability and the applicability of the road repair method using “do-nou” for communities in Kenya were assessed. The problematic sections with flat portions, sags and gentle slopes can be improved effectively using “do-nou”.

(8) “Do-nou” bags are not applicable to reinforce the base course of steep slopes, because the bags are soon exposed and torn, and thus, lose the reinforcement effect of the soil inside the bags.

(9) The earth reinforcement technology with “do-nou” was applied to rural road improvement to be conducted by the communities in rural areas of Kenya with locally available materials.

(10) An approach to improve rural roads of farm-to-market chain in developing countries was proposed specifically based on the established road repair method using “do-nou”. There are possibilities to disseminate “do-nou” not only in Kenya, but also in other developing countries.

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