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Evaluation of base course consisting of soil bags filled with fine-grained soil using the dynamic cone penetration test

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Abstract. In African countries, in order to improve the trafficability of earth and gravel road, locally available material-based and labour-based approach are regarded as one of the most practical measures. As one of the approaches, a base course reinforcement method using Do-nou, which is the Japanese term for soil bag, had been developed. In this study, the bearing capacity of base course built with Do-nou has been examined through the Dynamic Cone Penetration tests (DCP). The series of full-size driving tests have been conducted with varying base structures and compaction methods. The results of the DCP tests show that, only in the case of Do-nou reinforcement base with manual compaction, the strength distribution balance at the part of base course and subgrade within 800 mm in depth from surface was shifted from average to well after being subjected to traffic load. In the other two cases, the balance remained average. It presents that by reinforcing soil material with Do-nou bags, the base course compacted manually keeps the sufficient bearing capacity and well-balanced strength profile in depth comparing with those conventionally designed and constructed with equipment.

1 Introduction

In African countries, road networks connecting major cities and urban areas have been developed by the public sectors for macroeconomic development. However, such socioeconomic benefits frequently do not reach all rural areas as observed by the poor conditions of rural roads, which are the lifeline of rural communities as they connect households to social services and markets.

Considering the limitations of delivering public services in developing countries, Fukubayashi and Kimura [1] discussed an approach to improving rural access roads involving the self-reliance of communities along the roads. For this purpose, one of the main challenges for geotechnical engineers has been to build a road base course without equipment for compaction and using nonqualified base course materials on the soft subgrade. Thus, a spot improvement method with reinforcement of base course material with do-nou, the Japanese term for soil bag, was developed [1]. Fig. 1 presents a standard cross-sectional view of a road constructed with do-nou. Bags used for storing fertilizers, crops, Etc., locally available in

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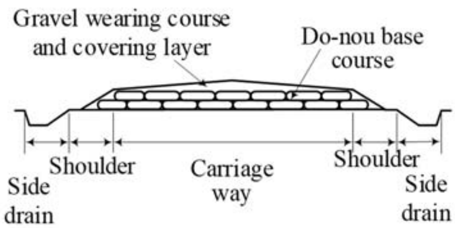

Fig. 1. Standard cross section view.

Fig. 2. Construction with Do-nou method in Uganda.

developing countries, were utilized as do-nou bags. The effect of do-nou on soil reinforcement and the corresponding soil reinforcement mechanism was proposed and theoretically quantified by Matsuoka and Liu [2]. Spot improvement using the do-nou method has been applied to several roads (Fig.2) and the practicability of this method has been confirmed [3].

In this paper, the performance of the base course built with Do-nou was evaluated with the Dynamic Cone Penetrometer (DCP) method, which were proposed to apply to low-volume road design by the Research for Community Access Partnership Program funded by UK Aid. The series of full-size driving tests have been conducted varying base course material, structure, compaction method and the moisture content. The result of the cases where the construction generated soil was utilized as base course material was presented by Fukubayashi, et. al. [4], here the result of the cases the crushed stones was utilized was presented in terms of the DCP analysis for comparison.

2 Full-size model driving tests

Full-size model driving tests were conducted in the Kibana Agricultural Science Station of the Faculty of Agriculture at the University of Miyazaki in Japan [4]. The type of the in-situ soil was classified as sandy elastic silt according to the ASTM Standard D2487 through the grain size distribution analysis. The physical and mechanical characteristics of the subgrade soil are presented in Table 1. According to a design manual for low-volume road developed in African countries, in this paper for one in Ethiopia is referred [5], the subgrade whose California bearing ratio (CBR) value was measured as 4.0, was classified as S2, the lowest class in the design manual describing the gravel base thickness.

In all driving tests conducted in this study, 2-ton truck with an empty load was used as the traffic load, and the number of continuous passes in one cycle was set to 300. The 300 passes were considered the annual average daily traffic, 150 passes in terms of round trips. Referring to the procedure to determine the design traffic class outlined in the design manual [5], the design traffic class was set to the class ranging from 0.01 to 0.1 million of the cumulative equivalent standard axle load.

2.1 Base course materials and do-nou bags

In rural Africa, the mechanically stabilized aggregate to meet the requirement stipulated in the road design manual, such as the crushed stones, is often unavailable. Therefore, in this test series, as one of locally available materials, the construction-generated soil, silty sand with gravel, was utilized as base course material which did not necessarily comply with the

Table 1. Characteristics of subgrade soil and base course materials.

	Subgrade	Base course	
Type of soil	In-situ soil	Construction-generated soil	Mechanically stabilized crushed stones
Soil classification	Sandy elastic silt	Silty sand with gravel	Well-graded gravel
Maximum size of grain (mm)	2.0	37.5	37.5
Plastic index	33.3	Non-plastic	Non-plastic
Maximum dry density (g/cm^3)	-	2.004	2.216
Optimum moisture content (%)	-	8.8	5.5
Designed CBR	4.0	-	-
Modified CBR at 95% degree of compaction	-	32	101

Table 2. Specifications of bags utilized as do-nou.

Material	Size of bag (cm)	Weight (g per bag)	Number of strings in 2.54 cm width		Tensile strength (kN/m)		Strain at yield (%)	
			Zonal	Warp	Zonal	Warp	Zonal	Warp
Polyethylene	62 x 48	58.0	10	10	11	10	22	17

requirement in the manual. In order to compare the performance of the base course to those built with the selected material, the driving test was conducted on the base course with the crushed stones as well. The physical and mechanical characteristics of the two base course material are presented in Table 1.

Bags made from polyethene with specifications listed in Table 2 were used as do-nou. These bags can be obtained even in rural area because the bags with the specification are utilized as wrapping 25 kg of fertilizer, crops, etc. After using the contents, such as crops, fertilizers, the empty bags were collected and utilized as Do-nou bags for road maintenance.

2.2 Base course structure and compaction method

The thickness of base course consisting of each material were decided with reference of the design catalog in the design manual [5] based on the strength of the subgrade of the test field, traffic class calculated based on the number of passes with the 2ton truck, and the modified CBR value of each base course material. The thickness for base course with the well-graded gravel and that with silty sand with gravel were decided as 225 mm and 250 mm, respectively.

For each material, the base course was constructed in three ways as shown in Fig. 3. In all the cases, the moisture contents of the material were adjusted to be the optimum moisture contents and spread to be three layers whose thickness was less than 100 mm. The first method was following to the construction management requirement by the manual [5]. Each layer was compacted with the hand roller with 600 kg weight and all the surface were subjected to the 6 passes of the roller.

The second method is the conventional road improvement practice by community themselves without any equipment. Each layer was compacted manually with just wooden rammer of 10 kg weight. 20 blows with the rammer per 0.4 m square area were applied.

The third method is to apply do-nou to reinforce the strength of base course material but still for labor intensive works. A certain volume of the base course material measured with the locally available bucket was put in the do-nou bags and the open end was tied in the consistent manner. After being laid on the ground, each filled do-nou bag were compacted with about 10 kg hand rammer applying 20 blows manually. With confirmation of the

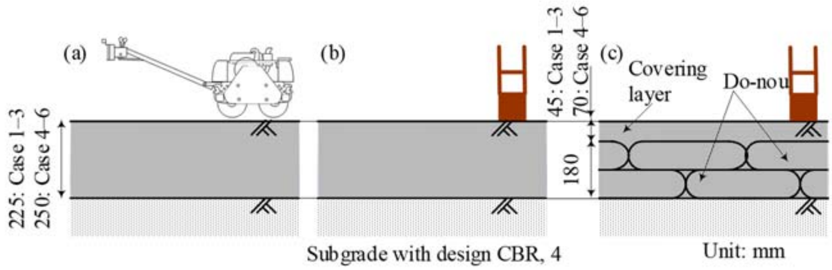

Fig. 3. Different base course structures for full-size model driving tests; (a) compaction with roller, (b) manual compaction, (c) manual compaction with reinforcement of do-nou.

Table 3. Full-size model driving test cases performed.

Case	Base course material	Thickness of base course (mm)	Structure of base course	Compaction method	Compaction degree (%)
1	Well-graded gravel	225	One layer	Compaction with pedestrian roller	97.1
2				Manual compaction with hand rammer	86.6
3			Two layers of do-nou + covering layer		Backfill in do-nou: 86.4 Covering layer:86.3
4	Silty sand with gravel	250	One layer	Compaction with pedestrian roller	95.5
5				Manual compaction with hand rammer	73.9
6			Two layers of do-nou + covering layer		Backfill in do-nou: 81.7 Covering layer: 75.2

dimensions of the compacted do-nou as 40 cm in length and width and 9 cm in thickness, it is considered empirically that the bags are tense enough to reinforce the base course material inside the bags sufficiently [4].

The first layer of do-nou were laid and compacted, then the voids between the adjacent compacted do-nou were filled with base course material and compacted manually, again. Then, the second layer of do-nou was laid and the same procedures were repeated. The covering layer of the base course material was applied on the second do-nou layer's surface so that the base course's total thickness reached to the same thickness as those constructed with the other two methods.

All the cases of the full-size model driving tests performed in this study are summarized in Table 3. The compaction degree of the base-course material and material for covering layer shown in Table 3 were examined by measuring the moisture content and the density with the drive cylinder method (AASHTO T204-90).

2.3 Traffic loading and measuring items

The test field was 3 m in width and 5 m in length. In each case of the driving test, all passes were made continuously at speed between 3 to 4 km/h, driving forward and in reverse along a channelized tire path.

In-situ strength of base course and subgrade in 800 mm depth was examined before and after the cyclic traffic loading of each case using the DCP with the specifications of ASTM D6951-M18. After the driving test, to examine the compaction effect caused with the traffic loading, the DCP tests were conducted at the channelized tire path where was intensively subjected to the traffic loading. Ampadu et al. [6] have introduced several applications of the DCP, such as an available tool that can be used for rapid verification of the levels of compaction on road project. Pinard et al. [7] have proposed an alternative method of pavement design for low-volume roads where the original DCP number (DN), which is penetration rate in mm/blow, is developing into fully balanced layer strength diagrams for various traffic categories of unpaved road.

3 Experimental results and discussion

3.1 DCP survey on the base course built with well-graded gravel and with silty sand with gravel

3.1.1 Dynamic cone penetrometer strength profile

The DCP strength profile and distribution of DCP Number (DN) value (mm/blow) in depth, before and after the driving tests were shown in Fig. 4 (a) for Cases 1–3 of the base course with well-graded gravel and in Fig.4 (b) for Cases 4–6 of the base course with silt sand with gravel. A typical result from the three penetration tests for each case was shown. With consideration of the limitation of the DCP, the variation of these results was reasonably less. The criteria for the roads where less than 2 heavy vehicles per day pass, which was the minimum category in the design manual for low-volume roads using DCP [7]. was also shown in Fig.4. The integrated DN defined as shown in the Fig.4 (b), were tabulated in Table 4 and 5 with the rate of decrease due to tyre pass compaction.

With both base course material, before the driving test, only the base course compacted with the equipment satisfied the criteria at the base course section. Through the compaction with the vehicle passes, the upper 200 mm from base course surface compacted manually with and without do-nou were strengthened and met the criteria. In Case-3, manual compaction with the reinforcement of do-nou bags, after the vehicle passes loading, the integrated DN was improved by 75%, while 42% in Case-2, 19% in Case-1. For the cases of the base course built with silty sand with gravel, the decrease of the integrated DN was around 30% in Cases 4–6, though the compaction and reinforcement method differed. In terms of DN value, when well-graded soil is used as base course material, do-nou reinforcement has shown a large improvement effect, while in the case of silty sand with gravel similar effect as non-reinforcement base.

Table 4. Integrated DN at the base course and rate of decrease for Cases 1–3.

Measurement items	Case 1		Case 2		Case 3		Criteria
	Before	After	Before	After	Before	After	
Integrated DN at Base	3494	2846	7990	4668	8872	2175	6225
Rate of decrease (%)	19		42		75		–

Table 5. Integrated DN at base course and rate of decrease for Cases 4–6.

Measurement items	Case 4		Case 5		Case 6		Criteria
	Before	After	Before	After	Before	After	
Integrated DN at Base	4779	3242	7619	5476	7925	5871	7050
Rate of decrease (%)	32		28		26		–

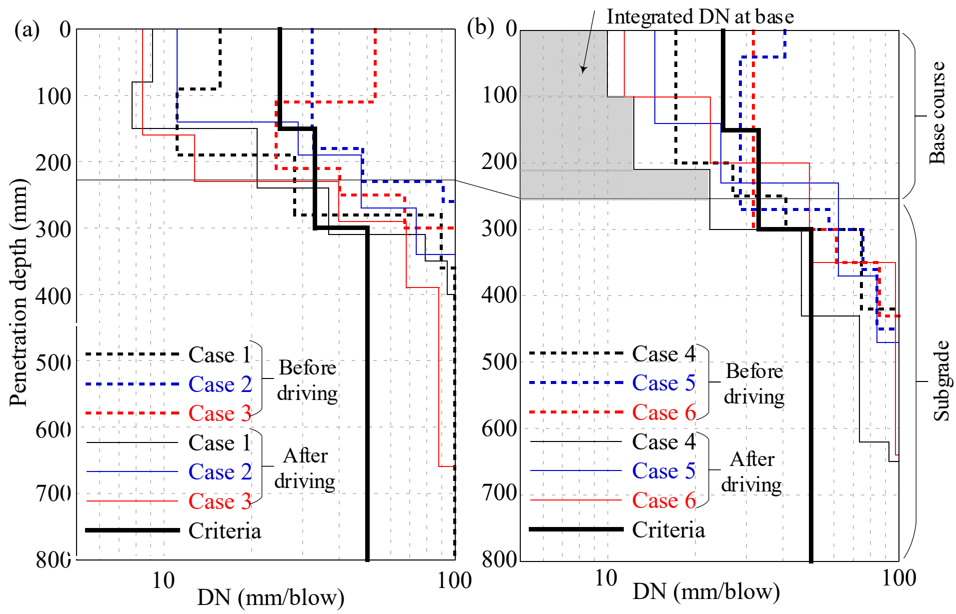

Fig. 4. Dynamic cone penetrometer strength profile before and after driving tests ; (a) in Cases 1–3, (b) in Cases 4–6.

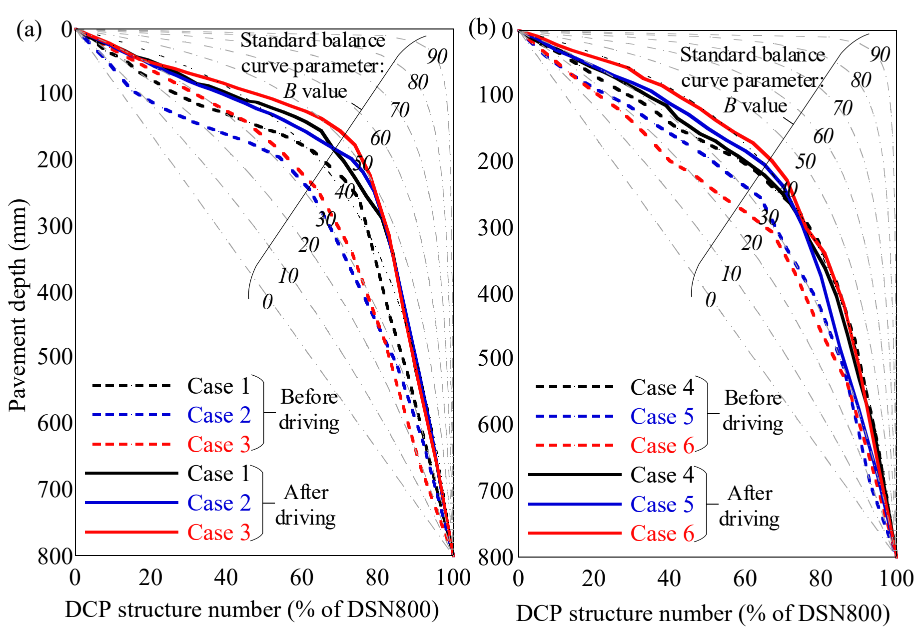

Fig. 5. Balance curve based on the results of the dynamic cone penetrometer (DCP) survey before and after driving tests ; (a) in Cases 1–3, (b) in Cases 4–6.

3.1.2 Balance curve based on the results of the dynamic cone penetrometer (DCP) survey

Referring to the DCP-DN method [7], the measured profiles of DN values were converted to the balance curves and shown in Fig. 5 with the standard pavement balance curves which parameters vary from 0 to 90. For drawing the balance curves, the number of DCP blows required to reach a certain depth, expressed as DCP Structure Number (DSN) that was a percentage of the number of DCP blows needed to penetrate the pavement to a depth 800 mm, which was defined as DCP Structure Number at 800 mm depth (DSN800). [7] determined the standard pavement balance curves from the following formula:

$$DSN = D\,[400B + (100 - B)^2]/[4BD + (100 - B)^2] \quad (1)$$

where *DSN* denotes the pavement structure number (% of DSN800) at the given depth (*D*), *B* is a parameter defining the standard pavement balance curve, and *D* is the pavement depth (%).

According to the DCP-DN method [7], the pavement structure could be classified with the nearest balance curve parameter (*B*) and the deviation (*A*) between the standard pavement balance curve parameter (*B*), identified as the best fitting, and the measured balance curves. The best fitting balance curve parameter (*B*) and the deviation before and after the traffic loading for Case-1–6, were obtained through AfCAP LVR DCP software v1.04 [8] with the DCP survey result and summarized in Tables 6 and 7. For the gravel road base course, it is said empirically that the balance curve whose *B* value is around 35 is the most reasonable balance [7].

Only when the base course was compacted with a pedestrian roller, for both cases of well-graded gravel and silty sand with gravel, the balance curve parameter, the B values, before traffic loading, exceeded 35. When the base course was compacted manually with and without do-nou reinforcement, after vehicle passes loading, the B values reached to more than 35. In Cases 1–3, the B values were resulting to be over 40, while Cases 4–6 were in the range between 35 and 37.

Due to the traffic loading on base course, the top part was compacted well and strengthened, resulting that the upper base course layers contributing to overall strength in all the cases. The B values has increased to around 35 for Case-5 and 6, while the deviation A decreased approaching the better-balanced base course structure. The base course built

Table 6. Best-fit balance curve parameter and deviation for Cases 1–3.

Measurement items	Case 1		Case 2		Case 3	
	Before	After	Before	After	Before	After
Balance curve parameter: *B*	35	42	24	41	27	42
Deviation: *A*	3087	2468	2861	2558	2087	1780
Description	Poorly balanced deep	Averagely balanced shallow	Averagely balanced deep	Averagely balanced shallow	Averagely balanced deep	Averagely balanced shallow

Table 7. Best-fit balance curve parameter and deviation for Cases 4–6.

Measurement items	Case 4		Case 5		Case 6	
	Before	After	Before	After	Before	After
Balance curve parameter: *B*	37	36	29	35	26	37
Deviation: *A*	2553	1917	2806	1429	2416	914
Description	Averagely balanced deep	Averagely balanced deep	Averagely balanced deep	Averagely balanced deep	Averagely balanced deep	Well balanced deep

with equipment showed the *B* value of more than 35 before the traffic loading. With the reinforcement of do-nou, the base course in Case-6 after traffic loading reached to the most balanced structure in the six cases.

As shown in Table 6 and 7, when the base course was reinforced with do-nou, the deviation from the balanced curves was the smallest among the three cases for each base course material. It can be said that the reinforcement with do-nou would contribute to the well-balanced strength profile of base course.

4 Conclusion

The full-size model driving tests were conducted to examine the performance of the base course reinforced with do-nou and compacted manually compared to the conventionally designed and constructed base courses under the low-volume road design manual. The following findings have been mainly obtained:

(1) Just after the construction of building the base course, the DCP strength profile of the base courses compacted manually both with and without reinforcement of do-nou did not satisfy the criteria in the design manual, while only that compacted with the equipment satisfied. However, after traffic loading, the top part of the base course in 200 mm depth at the tire path was well compacted, and all the structures satisfied the criteria.

(2) The base course reinforced with do-nou after 300 passes showed the most balanced strength curve in the depth of 800 mm based on the DCP survey results.

(3) The result of the DCP before driving showed that the base of all the cases were averagely balanced deep, while after loading, the result measured at the track only of the base reinforced with Do-nou showed the base was well balanced deep. It can be said that by reinforcing soil material with Do-nou bags, base course compacted manually keeps the sufficient bearing capacity and well-balanced strength profile in depth compared with those conventionally designed and constructed with equipment.

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