Bank-foot Water Channel Cleaning Work Truck
- Sediment absorbing robot and dehydration plant -

Tamiya Fukushima*, Tamotsu Ogasawara**, Minoru Kubota*, Masaru Totsuka***

*Kasumigaura Work Office, Kanto Regional Construction Bureau, Ministry of Construction Itako3510, Itako-cho, Namekata-gun, Ibaraki Prefecture,Japan
**National Highway Yokohama Work Office,Kanto Regional Construction Bureau,Ministry of Construction, Nishi-cho13-2, Mitsuzawa Kanagawa-ku, Kanagawa Prefecture, Japan
***DMW CORPORATION, New Products Designing sect, Miyosi-cho3-27,Misima-city,Shizuoka Prefecture, Japan

ABSTRACT

A 1.5-meter channel runs along the bank foot of Lake Kasumigaura, Ibaraki Prefecture. From fields and rice paddies that surround the area, soil drains into this channel and accumulates in the bottom. Unless removed, the accumulated soil degenerates the functions of the channel, and in the long run, possibly drain into Lake Kasumigaura.

With such anticipation, the Ministry of Construction has introduced the "Bank-foot channel cleaning work truck," a compact, highly mobile 11-ton truck installed with apparatuses necessary from absorbing to dewatering soil accumulated. Major advantages of the truck are: a suction robot, operated by wireless controller, runs pulling a suction hose by own driving system; and all apparatuses mounted on the truck are automatically-operated.

Each apparatus was designed based on calculation and experiment, and specifications were designed to satisfy each function. Special attention was paid to the design of the suction robot, as well as to the balance between apparatuses mounted on a limited space on the truck bed.

After factory testing, we conducted a site test, and confirmed that the truck has a soil collection capacity even higher than expected. However, repeated testing has shown that the truck requires further improvement. We intend to institute changes that will enhance its functions.

1. PREFACE

The quality of the water in Lake Kasumigaura in Ibaraki Prefecture is deteriorating. A major cause of pollution is sediment accumulated in the lake. The sediment is currently removed by dredging, but soil that continually flows into the water must be removed by a more efficient method in order to preserve the environment. A large portion of the soil that flows into the lake comes from farmland and rice paddies prevalent throughout this region. To prevent such soil flow, a 1.5-meter channel was built inside the bank-foot, surrounding Lake Kasumigaura nearly entirely. As much as 18,000 cubic meters of sediment accumulates in the channel each year, requiring regular removal to maintain the channels' function. To carry out this task, the Ministry of Construction decided to introduce channel cleaning work trucks.

This article outlines the development concept of the "Bank-foot channel cleaning work truck," manufactured in 1994 to remove sediment from the channel of Lake Kasumigaura. This article also recounts the process of building this truck, and introduces the truck's functions.

The terrain around Lake Kasumigaura is shown in Fig. 1.

2. DESIGN CONDITIONS

2-1 Site conditions

(1) Properties of the accumulated sand

Table 1 shows properties, moisture content,and specific gravity of the sand in the channel.

(2) Sectional view of the channel

Fig. 2 shows a sectional view of the channel.

(3) Total length of the channel -- 180 km

Approximately 90% of the total length will be cleaned under this project, excluding box-culvert are as and U-shaped channels.

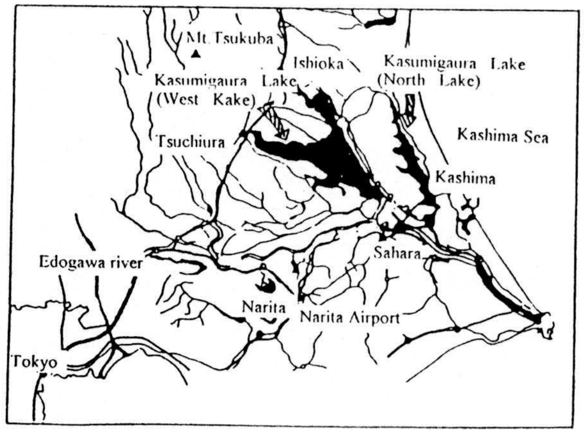

Fig.1 Map around Kasumigaura

2-2 Design conditions

(1) Removal capacity per hour
6 m3/h of bedrock soil

(2) Difference in height -- Maximum of 5m

(3) Power source -- Integrated into the truck

(4) Water removed from soil -- Returned to channel

(5) Cost of dehydration -- Designed to be less expensive than other currently available methods

Table 1 Properties of accumulated sand

Constituent of soil	Sand	Sandy soil	Silt	Clay
Moisture content(%)	23.1-23.8	28.6-46.9	39.6-79.4	45.6-61.4
Specific gravity of soil particle	2.1-2.67			
Accumulation speed	0.07m/year			
Amount required to be removed	18000 m^3/year			

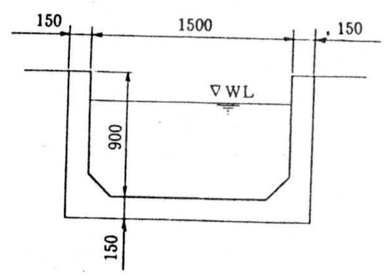

Fig 2 Sectional view of water channel

3. FUNCTION

Flow of channel cleaning by the "bank-foot channel cleaning work truck" is shown in Fig. 3. Currently, sediment collected by conventional suction truck is transported one load at a time repeatedly. The new system transports only dehydrated sediment, returning the water to the channel.

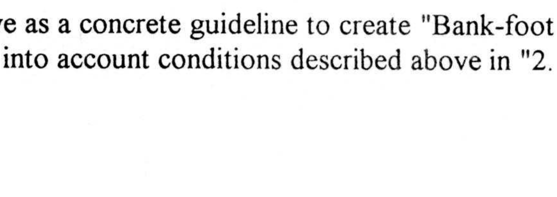

Fig 3 Flow of channel cleaning

4. DESIGN CONCEPT

4-1 Concept

Design concept (Fig. 4) was formed to serve as a concrete guideline to create "Bank-foot channel cleaning work truck." The concept took into account conditions described above in "2. Design Conditions."

4-2 Study of removing sediment

Work truck comprises two major units:

(1) Collection component

Collects soil and removes it outside the channel

(2) Soil dehydration component

Removes moisture from the collected soil (including water mixed during removal), and prepares soil to be transported to the sediment dump site.

Each function of the truck was tested to determine whether the collection component and dehydration component should be separated or integrated. Findings are shown in Table 2.

Both concepts of the separated units and integrated units are shown in Fig. 5.

After studying the findings, we have decided to adopt the separated type, whose collection component and dehydration component are operated independently.

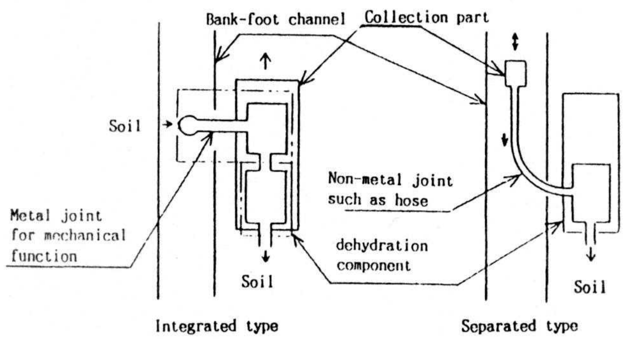

Fig.4 Design conception of channel cleaning

Tanks involved

Maintenance and control of the channel — Removal of sediment in the channel

Item	Requirement	Concept
Capacity/efficiency	Removal of sediment with capacity to remove bedrock soil at:6㎥/h × 5h/day × 150days/year=4500 /year	High capacity/ high efficiency
Additinal function	Easy to treat soil and water	Soil handling by machine
Benefit for workers	Clean,easy,safe	Remote control
Cost of operation	Less expensive by reducing labor cost Equivalent to a hydraulic shovel	Low cost

Machine makes work more attractive(stylish,mechanical,operation, high efficiency)

Fig.5 Sectional view of collection part and dehydration part

Comparison	Collection component and dehydration component are integrated (single unit)	Appraisal	Collection component and dehydration component are integrated (separate unit)	Appraisal
operation method	Move integrated unit	○	Move only collection component from one work area to another	○
System advantage	Capacity of collection component and speed of dehydration component must match	△	Stable collection capacity	○
Applicability to the site	Must be adjusted to various widths of channel	△	Can adjust to any width	○
	Difficult to use for different densities,and types of soil	△	Can use by operating collection component only	○
Benefit for workers	Similar to current hydraulic shovel operation	×	Very styrish work (attractive work)	◎
Mobility /setting up	Requires little opperation	○	Requires some preparation	△
Final appraisal	Not adopted		Adopted	

Table 2 Appraisal of collection part and dehydration

5. SYSTEM

Collection component and dehydration component are separately positioned and connected by a hose. Soil is collected through the hose. After deciding to adopt this system, we deliberated on two methods to collect soil. One uses pump pressure, and the other absorbs the soil by vacuum pump. Theory of pump pressure requires a pump be mounted on the collection component (hereinafter referred to as "suction robot"), whereas a vacuum pump should be loaded on the dehydration component.

We favored the vacuum pump system because: the channel is narrow; the vacuum pump can be used either underwater or partially immersed in water. The distance between the suction robot and dehydration component was limited, so workload per day is met.

The dehydration component was determined based on the traditional design which uses a vibrating screen and cyclone separators. The current method includes a bi-level vibrating dehydration system (large-mesh for upper screen, and fine-mesh for lower screen) and a single cyclone separator. Our latest system has a bi-level vibrating screen and three cyclone separators, because some area contains soil whose grain size is smaller than 75 μ m, and we seek to collect soil of size 20 μ m. Fig. 6 shows collection system flow. Following is a step-by-step explanation of the system based on the flow in Fig. 6.

(1) Sand mixed with water is absorbed by the suction robot and sent to the suction tank which is negatively pressurized by the vacuum pump.

(2) Switch valve is activated when suction tank A is filled with sand. Suction tank B begins to absorb sand.

(3) Suction tank A is exposed to barometric pressure, and the sand is discharged from the bottom of the tank, entering the vibrating screen (with rough-mesh).

(4) Suction tanks A and B repeat absorption and discharge through a switch valve.

(5) Vibrating screen (rough-mesh) removes foreign objects such as gravel and trash, and releases them into a dump truck.

(6) Slurry in the sediment tank is sent to cyclone No. 1 by underwater pump, concentrated, and released from the bottom of the tank to the vibrating screen (fine-mesh).

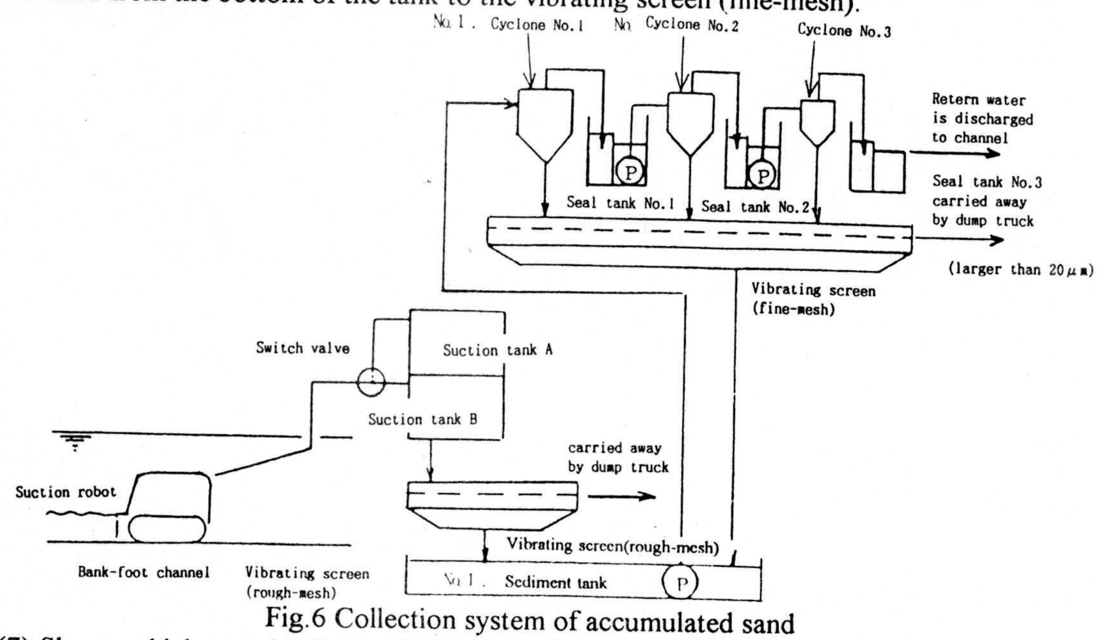

Fig.6 Collection system of accumulated sand

(7) Slurry, which contains fine grains, passes cyclone No. 1 and enters seal tank once. Then it is conveyed to cyclone No. 2 by pump.

(8) Similarly, slurry is further concentrated by the third, and smallest cyclone separators (size of the cyclone becomes smaller, and the number of the cyclone increases as the slurry travels lower.

Smaller grains are passed down by this process). Concentrated slurry is palletized and dehydrated via vibrating screen (fine-mesh), then released into a dump truck.

(9) Water that passed through cyclone No. 3 is returned to channel.

6. STRUCTURE AND POWER SOURCE

6-1 Structure

This machine must be highly mobile to be utilized along the channel that stretches over a long distance. To meet this requirement, we mounted all apparatuses on to an 11-ton truck. Positioning of each apparatus was determined considering power required, ease of use, weight balance, as well as moving sand mixed with water on the truck.

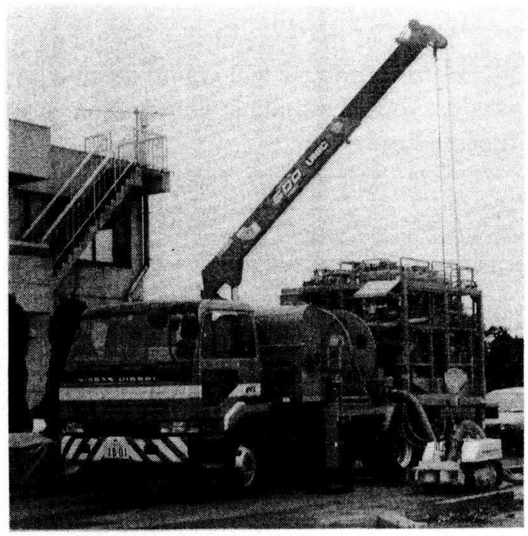

Fig.8 Bank-foot water channel cleaning work truck

Fig. 7 shows apparatus arrangement and Fig.8 shows Bank-foot water channel cleaning work truck.

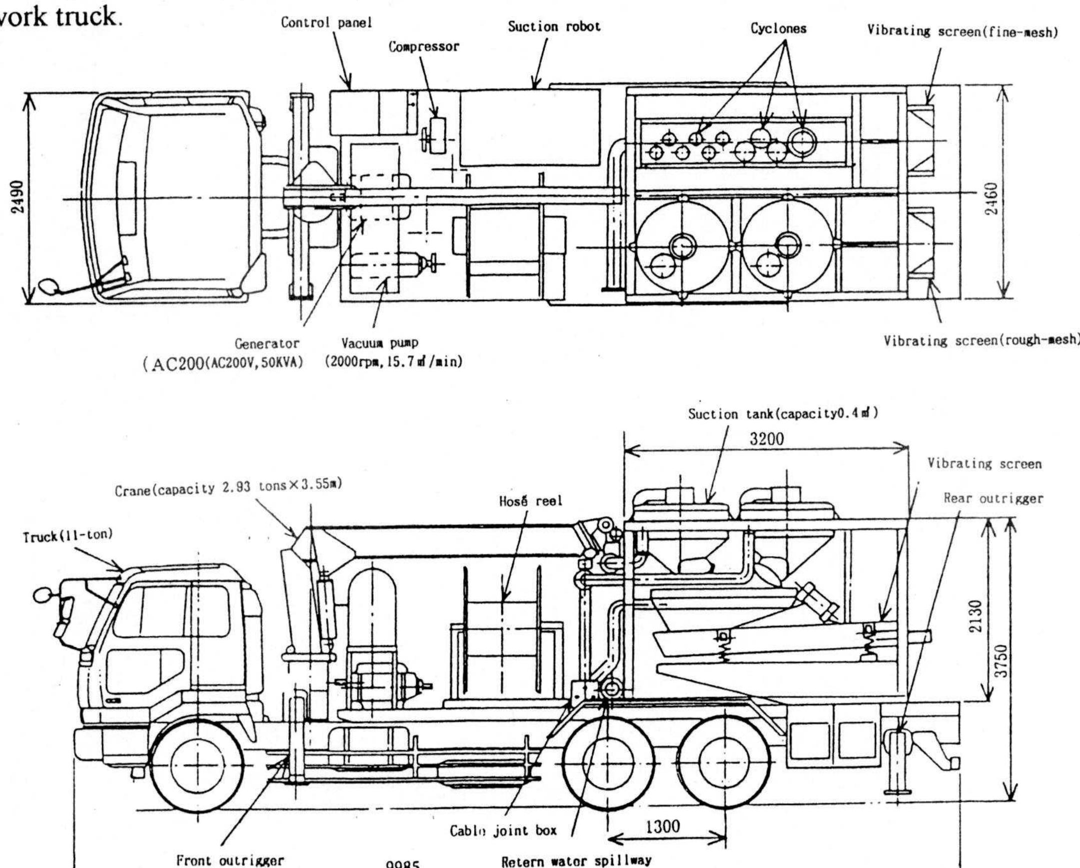

Fig.7 View of apparatus arrangement on truck

6-2 Power source

Some of the apparatuses, including generator, vacuum pump, compressor, and hydraulic pump (for outrigger and crane) receive power directly from the engine. Control power source, suction robot, vibrating dehydration systems, and cyclone pumps receive power from the mounted generator.

Since the suction tank valve and cylinders must respond immediately when they are activated, they are powered by air from the compressor. Fig. 9 shows the power system.

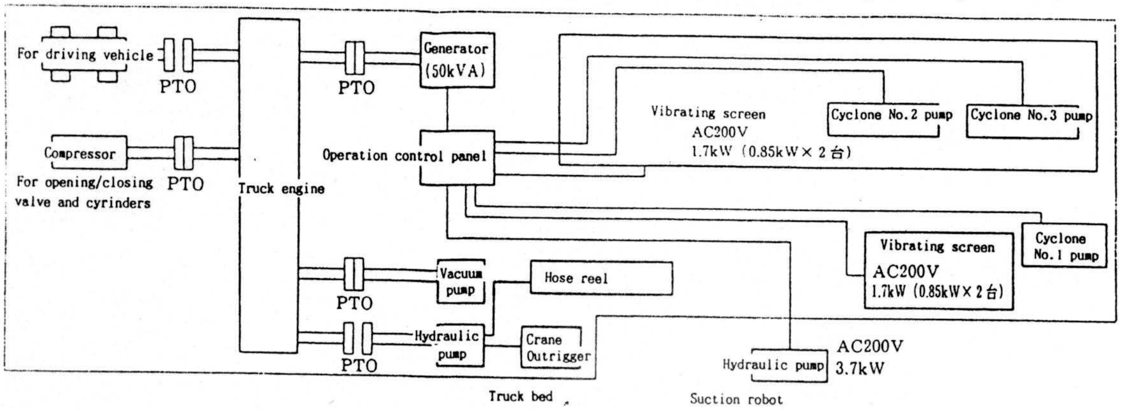

Fig.9 System of power

7. MOUNTED APPARATUSES

Major apparatuses are outlined below.

7-1 Suction robot

Worker must hold a hose while standing in the channel when cleaning work is conducted by conventional soil suction truck. This system eliminates this task, using an unmanned suction robot operated by wireless controller. The worker no longer has to enter the channel, and he can work in a safe, clean environment. Also, when the worker is holding a hose, soil cannot be mixed. But a suction robot has a rotating drum which is mounted with a hydraulically-operated motor at its end. Therefore, the suction robot can absorb tightly packed sand or clay by mixing them with water. Instead of screw type tip used for the current sand removing robot, this system adopts a rotating drum system. The opening is made small considering its absorbing function. The opening has two wings which rotate parallel to the ground to collect sand.

Drive/operation system	Electrical hydraulic system
Drive/operation system	3.7kw
Driving speed(two shifts)	Low speed:3.0m/min High speed:6.0m/min
Contact pressure	On land:0.11kgf/cm² ,underwater:0.09kgf/cm²
Maximum climbing grade	30 degree
Rotating dram	Rotation frequency:50rpm Torque:20kgf-m
Appropriate water depth	0.5-5m
Exterior size	1550(L) × 800(W) × 665(H)
Inlet opening	100 in diameter
Weight	On land:Approx.470kg,underwater:Approx.370kg
Mounted sensors	Water depth sensor,hydraulic pressure sensor, inclination sensor,drum position sensor

Table 3 Specification of robot

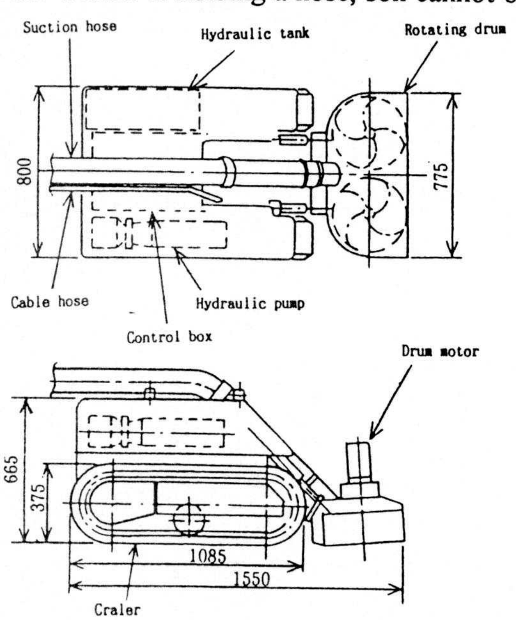

Fig.10 View of robot

Also, contact pressure is set small (0.09 kgf/cm2), so the truck can drive on silt sediment. Outer dimension of the crawler is large (approx. 380 mm) to render the truck able to negotiate bumps (max. 150 mm) in the channel.

Fig.10 shows exterior. Table 3 shows specifications.

7-2 Control panel

Due to their large number, all apparatuses mounted on the truck such as valve and cylinders are auto-operated. Worker follows the operation procedure to activate apparatuses, then observes the panel display. It takes two to three minutes for the system to commence suction after engine is activated as indicated in Fig. 11.

Control panel has an LCD touch-panel monitor on the front. Monitor displays six types of data, including surveillance, alarm, and manual. Among all displays, importance is placed on surveillance. For instance, apparatus under operation is displayed in red, the water is colored blue when being poured into the tank. This sends an unmistakable signal to the worker, and makes surveillance easy for him.

7-3 Wireless controller

A wireless controller is used to operate the suction robot, and to open or close the suction valve. The LCD of the wireless controller displays data received from various sensors including the inclination sensor which is mounted on the suction robot. Current robot operating wireless controller receives data, but does not transmit information that appears on the control panel. Therefore, information has to be relayed to the robot operator via transceiver. Operator of the new system can work more efficiently because he can receive information in real-time via system's transmission function. A wireless controller is shown in Fig. 12.

7-4 Dehydration system

(1) Suction tank

Suction tank has a continuous switching system, and has no direct effect on suction duration. Capacity of the tank is crucial. If capacity is too small, switching occurs too frequently, wasting time. If capacity is too large, the balance with dehydration system after soil is released is affected. Or muddy water bounces out from the vibrating dehydration system, and spills out from the open dehydration system. Considering these factors, we installed a suction tank with a capacity of 0.4 m3. Before mounting the tank to the truck, we conducted discharge tests to check if mud water falls down properly, and how much sand remains in the tank. The results were satisfactory.

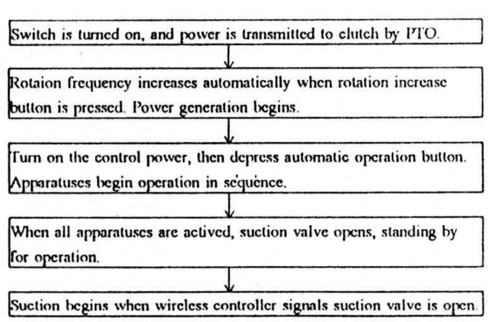

Fig.11 Flow of operation

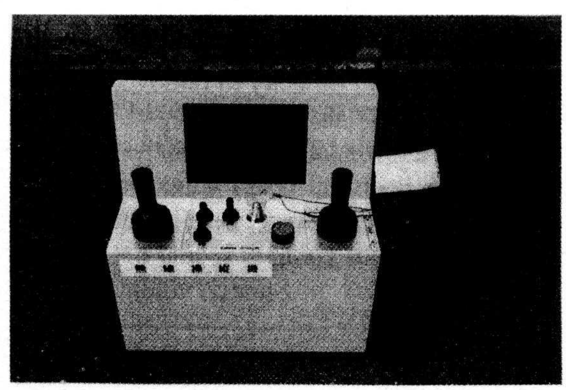

Fig.12 Wireless controller

Table 4 Specification of vibrating dehydration system

Type	Rough-mesh	Fine-mesh
Use	Trash, gravel	Grains larger than 20 μ m
Mesh size	2, 2, 1mm	0.3,0.3,0.1mm
Screen size	700 × 2700	
System	Wedgewire system	
Motor rotation	1000rpm	
Power unit	0.85kw × 2units	
Weight	660kg	

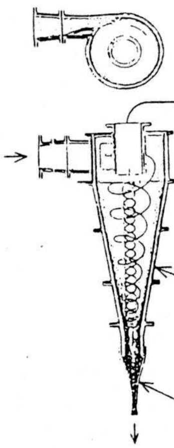

Fig.13 Sectional view of cyclone separator

(2) Vibrating dehydration system

Vibrating dehydration system uses two units, one with rough mesh, the other with fine mesh. The screen has three layers, and the mesh sizes of both units are determined depending on the purpose (Table 4).

(3) Cyclone separator

This cyclone separator grades and concentrates soil down to very fine grain, then releases it to the vibrating dehydration system. The bottom section has a synthetic rubber spigot regulator (Fig. 13). Cyclone is installed on the bed which can be lifted by crane approximately 4 meters above tank water surface. At this elevation, pressure inside the cyclone becomes negative. The negative pressure adjusts cyclone regulator to open automatically, and the soil goes through cyclone if it becomes highly concentrated.

(4) Vacuum pump

The size of the vacuum pump was determined based on test results. Fig. 14 summarizes the test equipment.

This test was conducted on the vacuum pump mounted on the soil suction vehicle: vacuum pump air flow was changed by adjusting engine rotation frequency; and the height of the tank was changed by lifting/lowering it with the crane. Fig. 15 indicates test relationship between vacuum pump airflow and suction volume when sand content is 27.2%.

On the other hand, due to the site conditions (2-1 Site conditions), the average moisture content in the sample sediment was approximately at 50 wt% (i.e. sand content is 50 wt%). And, as shown in Fig. 16, suction volume to absorb sand mixed with water should be 10 m3/h in order to obtain capacity to remove bedrock soil at 16 m3/h. Capacity at this rate is necessary because water is also collected with the bedrock soil, dropping sand content to about 35%. Actual per-hour suction time of the suction robot is estimated at 30 minutes, because robot does not collect soil when valve opens/closes, and when it is being maneuvered -- turning directions or backing up. Therefore, Q [m3/min] suction airflow necessary to obtain suction volume of 10 m3/h should be:

$$Q\ [\mathrm{m3/min}] = \frac{\text{Suction volume per hour}}{\text{Suction time per hour}} = \frac{10\ [\mathrm{m3/h}]}{30\ [\mathrm{min/h}]} = 0.33\ [\mathrm{m3/min}]$$

Sand content that can be handled by this suction airflow Q = 0.33 [m3/min] is 27.2% in the test, lower than 35% which is expected to be the sand content of the soil in the channel. We used the figure obtained by the test results in Fig. 16.

The curve showing the relationship between pump airflow and suction volume is estimated presuming tank is placed at the 5 meter level, which is design condition's maximum height difference. The curve was calculated from the data obtained when tank was lifted at 4 and 6 meters high. This curve indicates that vacuum pump must have a capacity of approximately 15 m3/h airflow. Based on these figures, we mounted a vacuum pump with rotation frequency of 2,000 rpm, and airflow rating 15.7 m3/h.

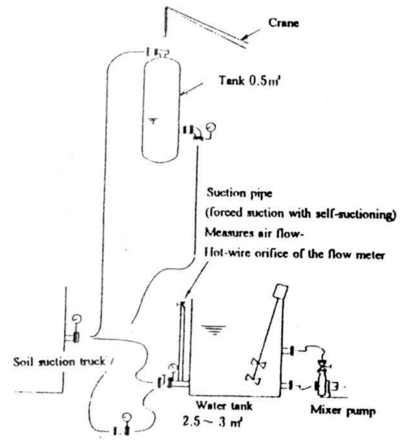

Fig. 14 Skeleton of test equipment

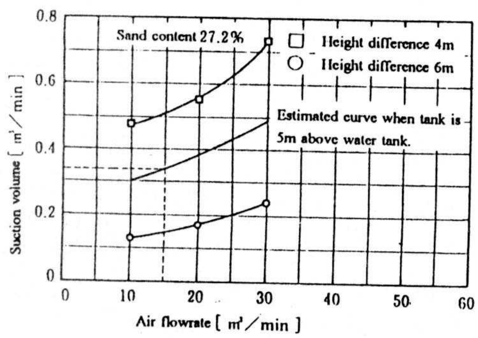

Fig. 15 Relationship between vacuum pump air flow and suction volume

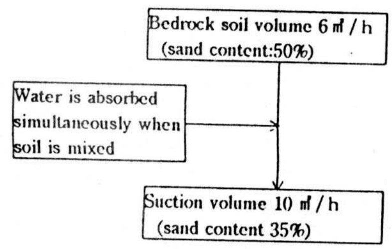

Fig. 16 Relation of bedrock soil volume and e suction volume

8.CAPACITY CONFIRMATION TEST

8-1 Factory test

Soil collection capacity of the channel cleaning truck was tested on approximately 30 cm thick sand. Sixty percent of the sand was grain sized 120 μ m. The sand was laid in a 5 m x 15 m water tank. The cleaning truck's capacity, i.e. operating a suction robot on the sand for about two minuets, was obtained by measuring the volume of the collected sand and sand content in the return water.

Table 5 shows test results on the volume of the collected sand and sand content in the return water.

The results indicate that the collection capacity is 6.7 m3/h, significantly higher than 6 m3/h outlined in the specifications.

Although the soil used in the test was sand, containing only 5% of small grains under 20 μ m, the sand content in the return water was satisfactory, as was the separating capacity.

Capacity in the third test is considerably higher than those in the first and second tests. Bumpy sand surface in the water tank is thought to be accountable for this difference. The robot, driven on an inconsistent surface in the first two tests, could not collect as much sand as in the third test when the surface was level.

8-2 Site test

Site test was conducted in the bank-foot channel in Nishiura, Kasumigaura. Sediment condition in the channel is shown in Table 6.

Test was conducted for three days. Results are shown in Table 7.

(1) Collection capacity

As indicated in the result, per-hour collection increased after each test. The reason for this is thought to be that the operator's skill improved after each test. On the third day, capacity of the work truck fully met expectation, exceeding the 6 m3/h mark set in the specifications.

(2) Operational function of suction robot

On the sediment where silt is accumulated as thick as 400 mm, truck skidded over the sediment, deteriorating its function. Also, some area of the channel bed was raised as high as 200 mm, which robot found impossible to climb by itself. In such case, we lifted the robot by the Unic crane mounted on the truck. Collection capacity is believed to increase further if the robot is used on a more advantageous bed surface.

(3) Clogging of the cyclone

Screen of the rough-meshed vibrating dehydration system was clogged by foreign objects. It caused the mud water to flow out of the tank. This unfiltered mud water then flowed into the cyclone, clogging it. Possible measures against such clogging include making a device to prevent foreign objects from getting caught by the screen, and standing a board against the edge of the vibrating dehydration system to prevent mud water from flowing into cyclone.

(4) Separation of sediment from water

We compared volume of the absorbed sediment with volume of the sediment loaded in the dump truck, and studied grain distribution of the collected sediment as well. These results indicate that the separation function meets our expectation. However, channel has large amount of grains smaller than 20 μ m. Sediment collection will become more efficient when an apparatus to retain grains under 20 μ m is developed in the future and combined with this system.

Table 5 result of collection test

	Operation time [s]	Removed sand [㎥]	Removed sand per hour [㎥/h]	Sand content in retern water [%]
First test	120	0.19	5.7	0.2
Second test	120	0.18	5.4	
Third test	130	0.32	8.8	
Average	-	-	6.7	-

Table 6 Sediment condition

Thickness	400mm
Moisture rate	82.3%
60% of the grain size	20-30 μ m
Other	•Channel bed has height difference of about 200mm •Foreign objects such as tree twigs are included in the sediment.

Table 7 Test result

	Collection volume [%]	Per-hour collection [㎥/h]
First day	2.72	2.53
Second day	3.84	3.84
Third day	7.41	6.18

9. CONCLUSION

Completed work truck is highly mobile, with all necessary apparatuses installed compactly on an 11-ton truck. Tasks that require the operator to enter the channel can be conducted by a remote controlled robot instead. This work truck not only can increase work efficiency and reduce cost, it can also bring change to the image of this work. Until today, more importance has been placed on the development of machines than on increasing the attraction of the work. Work truck makes this job appear stylish, eliminates so-called "three-D concept" (dirty, dangerous, difficult), and creates "attractive work," which was included in the design concept.

We have now completed a first site test to study how suitable the truck is to the task. We will carry out another site test after solving problems illuminated in the first test, improving functions each time toward the completion of an ideal work truck.