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Experimental studies to estimate sea bed friction on a mining machine

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Abstract
In this paper, the technological advancement of ocean mining industry is used to excavate sea floor massive sulfides. With the steady development of technologies, explorations are done at deep sea and large deposits of mineral resources like manganese nodules, sulfide deposits are found out. These new findings envisaged the deep sea mining activities further. The design and development of DOROSMIN (Deep Ocean Remotely Operable Mining System) helps to conduct experiments to understand about the soil-machine interaction.

INTRODUCTION
Ocean is nature's precious gift to humankind. It provides a large number of useful things for the existence and survival of life in the planet. It acts as a thermostat and heat reservoir, leveling out the temperature extremes, which would prevail over the earth without its moderating influences.With the steady development of technologies, explorations, are done at deep sea and large deposits of mineral resources like manganese nodules, sulphide deposits are found out. These new findings envisaged the deep sea mining activities further.

Mero (1978) gives a detailed report of the history of ocean mining around the world. **Chung (1996)** details the recent improvements in the deep ocean mining system specifically for manganese nodules upto 6000 m water depth. Characteristics of various mineral resources like manganese nodules were explained in detail. The paper says about the various parts of mining system and the integration between the parts. **Khadge (1995)** describes the geotechnical studies for siliceous sediments from the Central Indian Basin. The work was carried out by National Institute of Oceanography (NIO), India. Studies were done on sediments from 5000-6000 m depth in Central Indian Basin. **Noorany and Fuller (1982)** explain the drag resistance caused by soft clays when metal tools are ploughed through the soil/clay at various velocities. The experiment was done at San Diego State University for developing soil-machine interaction criteria for the design of a deep sea manganese nodule collector system. **Paul and Ghosh (1999)** presented the design of a deep seabed miner which is intended to mine polymetallic nodules from the seabed.. The paper explains about the various resistances acting on an underwater mining system and the calculations of the power required for such a machine.
The present study is done to find the drag forces acting on DOROSMIN (Deep Ocean Remotely Operable Mining System) while it is being towed at increased speeds. In addition, the seabed friction offered by the soil to the mining teeth is to be found out by experimental methods and to conduct experiments to understand about the soil-machine interaction.

EXPERIMENT METHODOLOGY
The mining system is designed to work at a depth of 5000 – 6000 m below the sea level. The machine is being towed by a mother vessel. The front inclined portion of machine has got teeth which ploughs

through the soil and accumulate the manganese nodules to the corner where the jet pump connected will pump the slurry with nodules to the top. While the machine is being towed, the frictional resistance caused by the soil on the teeth was studied experimentally. There are seven channels in the front inclined portion. On each channel there are 28 teeth attached which do the mining job. The teeth are aligned parallel to the towing direction and the channels are inclined at an angle of 35 degree to the tow direction. Among the seven channels, one channel was taken for the experiment. Figure 1 shows a single channel with teeth.

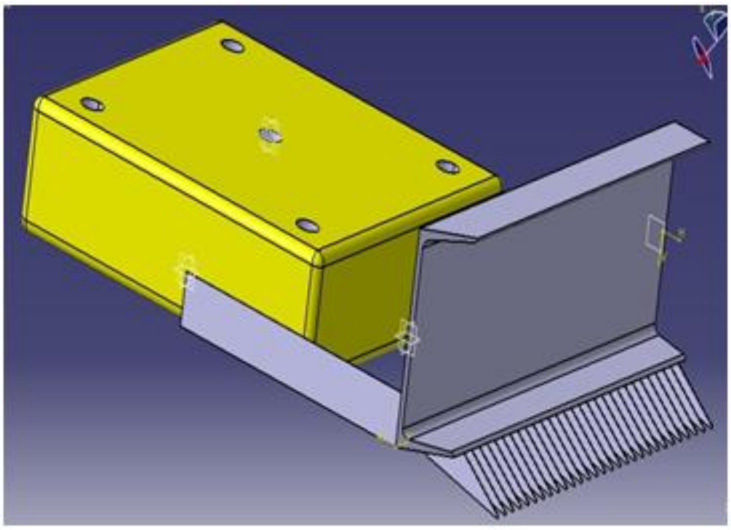

***Fig 1** Single channel with teeth*

The seabed having similar soil properties at a depth of 5000 m was to be simulated in a tank and the teeth was towed through the soil. A winch is used to pull the teeth fixed on a carriage. A load cell connected between the carriage and the pulling cable of winch will give the force required for pulling at various conditions. Schematic views of the experiment setup is shown in Figure 2.

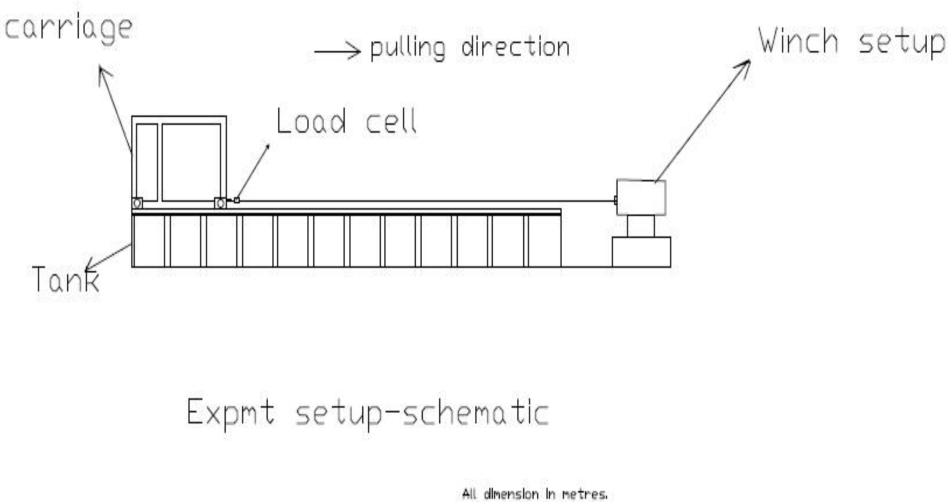

***Fig.2.** Experiment schematic*

The tank is made with mild steel of dimension 8 (L) × 1.3 (B) × 0.6 (H) m. Railings are provided a width of 45 cm for the smooth running of rollers of the carriage. Carriage is a mild steel structure which has rollers to move over the railings on the tank while being pulled. Provisions are made on the carriage for fixing the testing teeth channel. The crawler is designed to work at a depth of 5000-6000 m. Geotechnical investigations at such depths (Khadge, 2001) say that the sediments are silty clays composed of clay minerals like illite, smecite, chlorite, kaolomite etc. and has been observed that the sediments are found to be more siliceous at such depths. The shear strength of soil varies between 2.08 kPa to 0.75 kPa in 0-5 cm layer of seabed. Even though the shear strength of soil at such depths are very less, the soil offers some resistance before failure. (Khadge,1999). In order to study about those resistances offered by the soil, such soil conditions are to be simulated in the test bed also.

Bentonite Mixture

For the simulation of test bed it was found that bentonite clay is a good material hence it falls into the smectite group of clay. Bentonite is natural clay formed by the weathering of volcanic ash and belongs to the alumino-silicate group of minerals. It is a highly water absorbent material. Bentonite is mixed with water and the slurry is used as an artificial sea bed. The shear strength of such a bed can be adjusted with the amount of water used for mixing. Bentonite powder was mixed with water in the ratio 1:4.For thorough mixing, motorized equipment was used as shown below figure 3.

Fig. 3 *Bentonite mixed with water*

METHODOLOGY

The experiment setup is arranged by fixing the teeth to the carriage, which rests on the railings of the tank. One end of load cell is connected to the nylon rope of the winch and the other end was connected to the carriage. The data cable from load cell was connected to a display unit and then to the laptop for logging the data. Experiment was done for no load condition and loaded condition. No load condition means the teeth are not immersed in the soil and loaded condition implies the teeth immersed in soil. Without the teeth touching the soil bed, carriage was pulled for a distance of 6m and the time taken was noted along with the force value readings from the load cell. The above procedure was repeated by keeping the teeth immersed in soil also for 0.5kPa and 1kPa shear strength of the soil. Graphs were plotted between force values and the corresponding time. The difference between the no load condition and loaded condition gave the soil friction resistance acting on the teeth of the system. The mining system has seven numbers of teeth. Hence the total soil friction resistance was obtained by multiplying the soil friction value of single teeth with seven.

RESULTS

The time taken by the carriage for moving through 6m was noted as 57 seconds. Graphs were plotted with the force values and the corresponding time period which are shown in figure 4 and 5. It was observed that though there were irregularities in each graph, the trend was found to be common for loaded and no loaded condition. Hence, it was decided to take a linear trend line of each graph and plotting again for summarizing the results (figure 6). Friction coefficient graphs were also plotted with the data obtained and taking the weight of the carriage and teeth as 525 kg which is shown in figure 7. The difference between the initial values between any immersed condition and no load condition was taken as the soil friction resistance acting on single teeth of mining system.

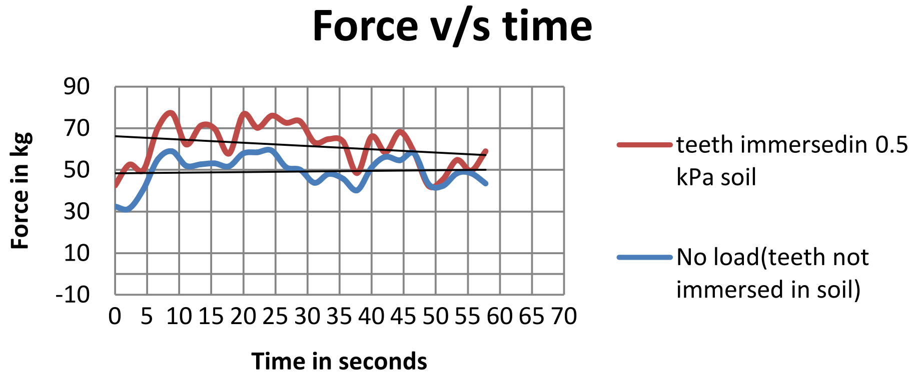

Fig.4. *Comparison of no load and teeth immersed in 0.5kPa soil*

1) Frictional force acting on the teeth when it is moving through 0.5kPa soil is 157N
2) Frictional force acting on the teeth when it is moving through 1kPa soil is 216 N

There are seven teeth in the mining system. Considering the 1kPa soil, the total friction force acting on machine while it is being towed = 216×7 = 1512 N

It was found that friction coefficient increased by 3% when the teeth was immersed in 0.5kPa soil compared to the no load condition (when teeth is not immersed in soil).Also when the teeth was immersed in 1kPa soil, friction coefficient was observed to increase by 4.5 % compared to no load condition

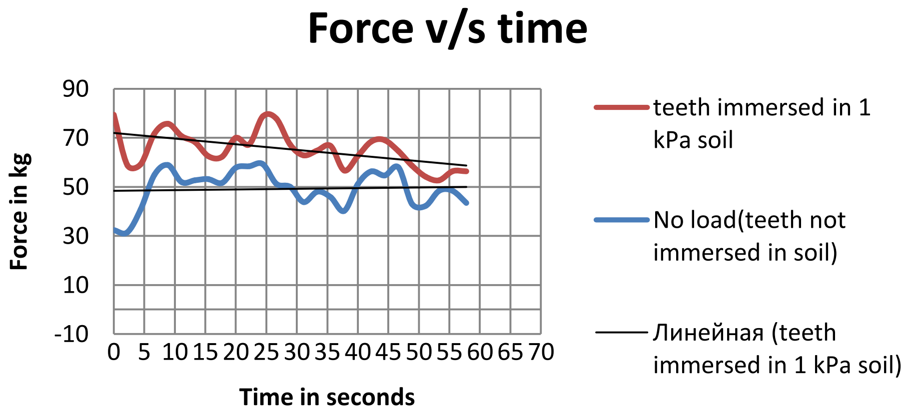

Fig 5. *Comparison of no load and teeth immersed in 1kPa soil*

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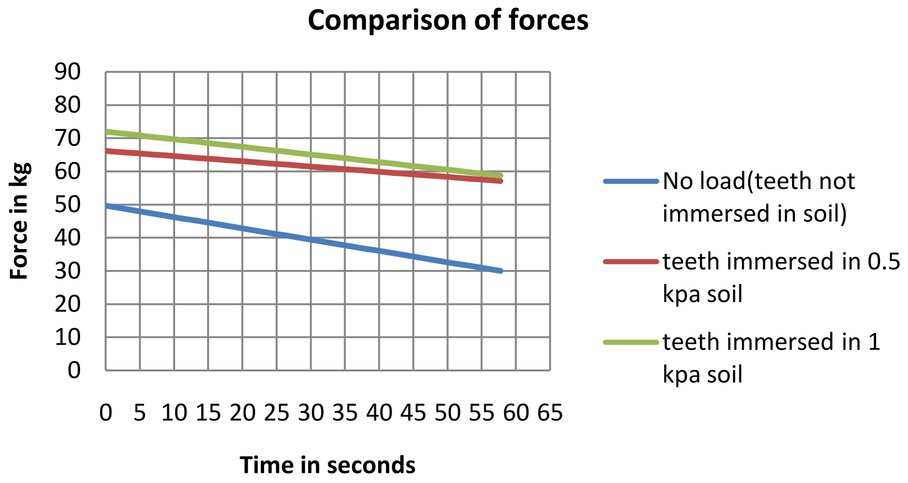

Fig.6. *Comparison of forces of experiment*

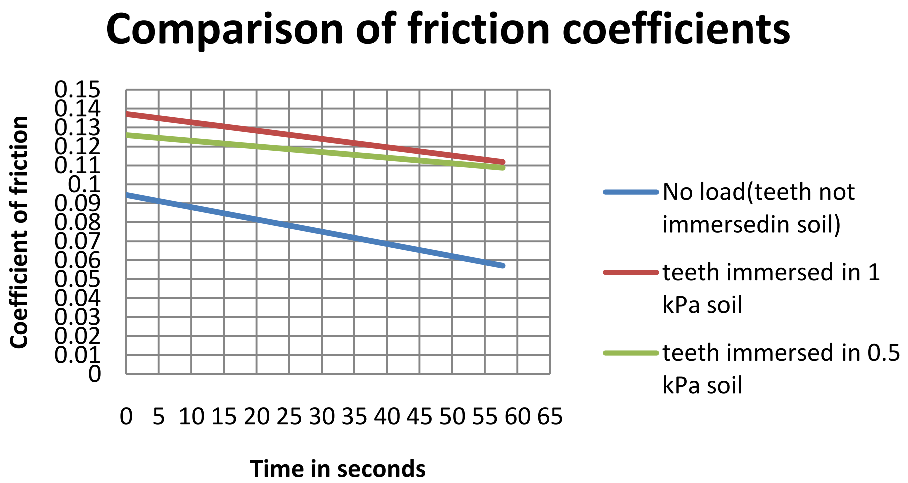

Fig.7. *Comparison of friction coefficients*

CONCLUSION

Experimental studies helped to understand about the sea bed friction acting on the teeth of DOROSMIN. The total resisting force due to sea bed friction was obtained experimentally as 1512 N. Thus the total hydrodynamic drag and sea bed friction acting on DOROSMIN in its operating condition was obtained as 3236 N. Experiments were done to find the soil friction acting on the teeth of DOROSMIN while it is mining in seabed.

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