Development of a Tractor Operated Soil Compaction Measurement Device

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Abstract: **The heavy agricultural equipments cause high compaction in the top layer of the soil in agriculture. As the present method of soil compaction measurement is not ergonomically good practice by hand-held penetrometers either by static or dynamic. In India, the compaction data are taken by hand operated penetrometers generally which has certain limitations and more chance of error as manually operated penetrometers with dial gauge or digital display type penetrometers. However, some of the developed countries are using automatic multi-probe type sensor for collecting data for soil penetration resistance. Due to the limitations in hand held penetrometers, a tractor operated sensor based soil compaction measurement device has been developed which will increases the volume of data for a particular area and reduce human factor of error and upgrade the quality of measurement used by Indian scientific community for agricultural soil compaction so that scientists can correlate the crop parameters to be grown and this data can be used in agricultural machine design with different crop parameters and hence, recommendations for a particular machinery for a particular area or crop can be generated. Soil compactness and soil moisture content maps will give a colour coded maps of an area/particular region so that specific crop or the area needs attention on priority basis.**

Key Words-soil compaction ; penetrometer; sensing machines; cone index

I. Introduction

The present era in Indian agriculture is of precision farming and all the scientific brains are working towards of resource conservation through right amount, right place, right time and right quaintly of placement of inputs for optimization of productivity. Indian agriculture has witnessed a definite shift towards high hp tractors. Further, the heavy equipments such as combine harvester, sugarcane harvester and other specialized machineries have been introduced on Indian farms. The weight of self-propelled combines in India ranges from 6 to 7.5 tonne while the sugarcane harvesters with weight of 9 to 12 tonne may compact soil up to 300-400 mm depths, particularly when working under moist soil condition. The use of heavy farm machines that mostly cause high compaction in the top layer of the soil in a short time, whereas, the heavy and frequent use of these farm machines compact the subsoil in the long term regardless of the soil type. This may reduce the yield of effected crop.

Soil compactness and soil moisture content are major factors for crop growth and base for many scientific studies. For precision application, if database of soil compactness and moisture content maps of a particular region is available, then the policy makers, planners and farmers can approach in the right direction for application of inputs in a right way for any particular crop. Similarly, these parameters are measured inside the soil, generally upto 400 mm depth, which is relatively tough and cumbersome in most conditions. Soil compaction has most significant effect on yield or yield potential of crops. The inability of roots to penetrate compacted soil layers will result in decreased yield. Compacted soils often have higher subsurface soil moisture contents because soil water is unable to drain away freely and air movement in the soil is restricted. This reduction in internal drainage generally leads to surface ponding which may results lower yield. Therefore, there is a need of soil compaction database, so scientists can deal with the problems encountered due to unavailability of data.

A. *Measurement of Soil Compaction*

In agriculture the soil compaction is measured generally by two methods/means i.e. (i) core cutter method in which bulk density is measured and (ii) by penetrometer in which soil resistance is measured in Pascal. Penetrometer should penetrate into the soil (generally up to 400 mm depth for agricultural purpose) with a constant speed and in vertical position. However, in most of cases, penetrometer is used by different non technical agricultural workers and the penetration speed depends upon physical power of agricultural worker, desire to work, angle of entry of probe etc. Further, most of the time, it is difficult to penetrate the Penitrometer inside the soil by one person, so more persons involved to apply the required force, which again increase complexity to acquire constant force for penetration of Penitrometer inside the soil and further it is not ergonomically good practice. Another method to obtain the soil density is by core cutter method which is labour intensive and accuracy of experiment reduces with more replications.

B. *Measurement of Soil Compaction by Penetrometer*

There are two general types of hand-held penetrometers: Static and Dynamic. Both measure soil resistance to vertical penetration of a probe or cone. The distinction between the two lies in how force is applied to the cone.

a. *Static Cone Penetrometers*

These measures the force required to push a metal cone through the soil at a constant velocity. The force is usually measured by a load cell or strain gauge coupled with an analog dial or pressure transducer for readout. A static cone penetrometer with a 300C cone has been recommended by the American Society of Agricultural Engineers, as the standard measuring device for characterizing the penetration resistance of soils [1]. It is portable but hard to penetrate into soil, hardly maintain the recommended speed and chance of error are more during data reading during operation.

b. *Dynamic Cone Penetrometers*

In these types of penetrometer, a known amount of kinetic energy to the cone is applied which causes the penetrometer to move a distance through the soil. The depth of penetration is recorded for each hammer blow until a maximum or desired depth is reached. Penetrometers driven to depths greater than approximately 300 mm may be difficult to remove from the soil. It is heavier than static type cone penetrometer.

C. *The present status of soil compaction measurement devices*

In India, the compaction data are taken by hand operated penetrometers generally which has certain limitations and more chance of error. Generally, manually operated penetrometers with dial gauge are used. Whereas, some institutes are also using digital display type manual penetrometers. However, some of the developed countries are using automatic multi-probe type sensor for collecting data for soil penetration resistance. Reference [2] developed a multi probe soil cone penetrometer in USA that could quickly measure cone index across the row from a trafficked row middle to an un-trafficked row middle. This is a tractor mounted instrument and penetrometers are pushed into soil by help of a hydraulic cylinder. Reference [3] developed a combined cone penetrometer–time domain reflectometer (TDR) probe in USA which was capable to measure soil water content and bulk density simultaneously. This is manually operated instrument and construction of device different than ASAE standard cone size. Reference [4] developed a trailer mounted penetrometer in which hydraulic cylinder was used to insert the penetrometer to a maximum depth of 950mm in Columbia, Missouri. In addition to that, this cone penetrometer is also having electrical conductivity (EC) sensing tip which measure EC of soil simultaneously. However, its cone size differs from ASAE standard cone size hence, required some relation to correlate the data. Reference [5] developed a cone penetrometer as described in the ASAE standard and mounted beneath the load cell unit. The hydraulic components are powered by the tractor hydraulic system in Iran. Flow control assembly with pressure compensated and flow regulator valves were used to obtain a desired constant speed of penetration. A depth transducer mechanism, by using two pairs of photodiode sensors to acquire an electrical signal proportional to the depth of penetration. Reference [6] developed an electronic penetrometer mounted on the tractor consists of a load-cell and a depth sensor in Turkey.

II. Concept of A Tractor Operated Sensor Based Soil Compaction Measurement Device

Penetrometer has some limitations which has been mentioned in previous paragraphs. Some of these are removed i.e. human error while taking data with provision of sensor and datalogger, but insertation of penetrometer with recommended speed is still a cumbersome and tedious job. The above said limitations with hand operated penetrometer can be overcome by a power operated automatic penetrometer with recording device. So, there is a need of instrument for measurement of compactness of soil so that scientists can correlate the crop to be grown and the research planning with authentic data in a particular area.

Thus the use of tractor hydraulic system has been considered a option for insertation of penetrometer into the soil with recommended constant speed. The tractor's hydraulic operated penetrometer with automatic data recording system will give more authentic data in less time and reduce drudgery of workers. Further, it will increases the volume of data for a particular area and reduce human factor of error and upgrade the quality of measuring instrument used by Indian scientific community for agricultural soil compaction measurement.

This instrument will provide a database of compaction of research area in a particular research station, agricultural university, college, KVK etc. and this will help scientists to correlate the crop parameters to be grown and the research planning with authentic data. In addition to that, this data can be used in agricultural machine design with correlation of different crop parameters, recommendations for machinery for a particular area or crop (good soil structure -zero tillage, hard pan -sub-soiler etc.). So to work to address on specific problems, a compaction measurement device by using hydraulic system of tractor for pushing penetrometer inside soil at recommended constant speed and at the same time measurement was recorded by data logger with the help of sensors will lead the problem one step towards a finite solution. Soil compactness and soil moisture content maps will give a colour coded maps of an area/particular region so that specific crop or the area needs attention on priority basis.

III. Development of Machine

The concept of modified penetrometer with data acquisition system is shown in Fig. 1 and Fig. 2.

A. *Calculation for Hydraulic Cylinder*

It is reported that the maximum soil resistance after which the plant root ceases to grow is 5 MPa. So this value is taken as design factor in design part calculations. Since, this resistance will be acting on soil penetrometer cone tip which has effective area of 322.7 mm^2 [1], thus,

Net force required to overcome the soil resistance,

$$F_r = \text{Soil Resistance x effective area}$$
$$= 5 \times 322.7$$
$$= 1613.5 \text{ N}$$
$$\cong 1615 \text{ N} \quad (1)$$

This is the force required and is to be transferred with the help of hydraulic actuators i.e. hydraulic cylinder. For designing hydraulic cylinder, its bore and stroke length dimensions need to be calculated. As the penetrometer needs to go upto the depth of 600 mm, stroke length of cylinder is taken to be 600 mm. Therefore, considering design, the bore diameter of 40 mm is selected to satisfy the design requirements.

Now the force (F_p) produced by a hydraulic cylinder is a product of its effective area and the differential pressure (Δp) across its ports.

$$\Delta p = \frac{Fp}{A \times \eta hm} \quad (2)$$

Where Δp= Pressure difference across cylinder ports (MPa)

F_p= Cylinder force (N)

A= Effective area of a cylinder (mm^2) = $\pi D^2/4 = \pi (40)^2/4 = 1256$ mm^2

ηhm= Cylinder hydraulic/mechanical efficiency = 0.85

$$\Delta p = \frac{1615}{1256 \times 0.85} \quad (3)$$

$$\Delta p = 1.5127 \text{ MPa} \quad (4)$$

Hence, pressure difference across cylinder ports required is 1.5127 MPa and this pressure is obtained with proper design of hydraulic system.

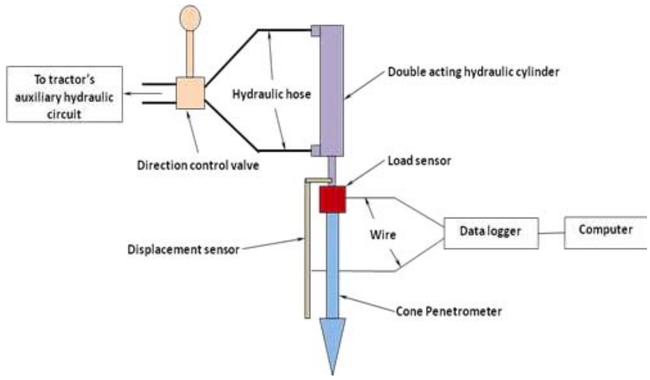

Fig. 1 a. Concept of modified cone penetrometer

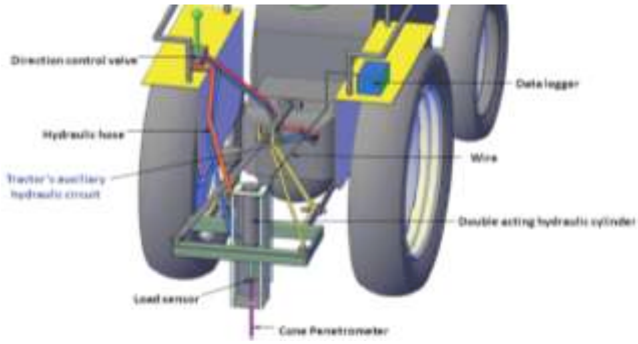

Fig. 1 b. Machine fixed with tractor hydraulic system

B. *Design of Frame*

The hydraulic cylinder mounted on a frame which will be able to slide vertically as well as horizontally over another frame which facilitates the operator to take the measurement up to 600 mm depth vertically as well as having the arrangements to move laterally to another position as per the requirement. All the loads i.e. both dead and live are ultimately to be bear by the horizontal beam, hence it is most important to check it for failure. As per previous calculation 2500 N of force is acting on the centre of gravity of hydraulic cylinder which is at the distance of 50 mm from the axis of the beam. This force will be inducing 2500 x 50 = 125 Nm of torque. Also the weight of the columns welded on the beam will induce a load of 50 N each at their respective mounting place. Hence this beam is under combined load of bending and torsion and designed considering these loads. As a good research's ultimate benefit must go to farmers level. Therefore, a first prototype of a tractor operated sensor based soil compaction measurement device has been developed. A lab model of the same is also under progress so this testing can be done in lab also for further simulation work.

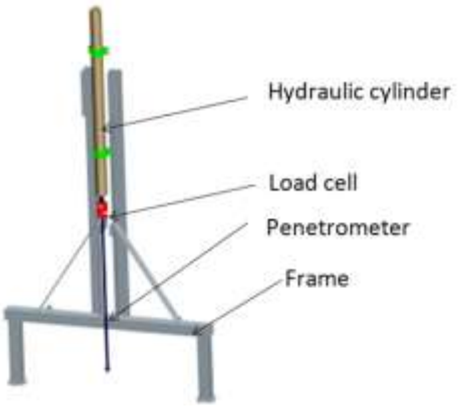

Fig. 2 a. Isometric View of Machine

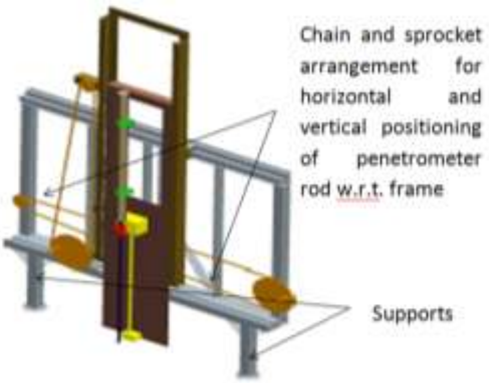

Fig. 2 b. Arrangement of lateral movement of machine

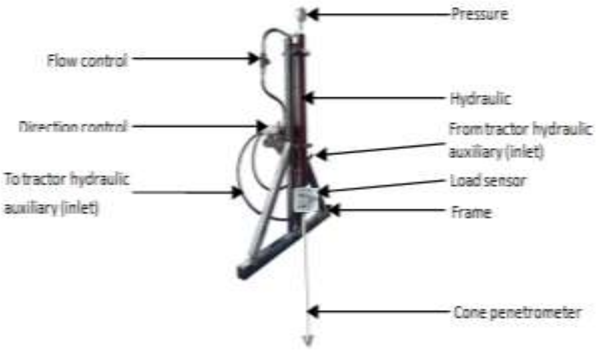

Fig.3 First Prototype of Automatic Penetrometer

C. *Technical Details*

The machine consists standard Penetrometer, double acting type hydraulic cylinder (600mm x 40mm) having pressure developing capacity 5000 kPa (725 psi), direction and flow control valve for hydraulic fluid, S-type load cell, LVDT type displacement sensor for 400mm depth, multi channel type data logger and direction control valve. The instrument uses the tractor's three point hitch to mount and hydraulic system as a power source.

It has less number of moving parts so less wear and tear of parts is there. It will be an fully automatic sensor based instrument which will reduce drudgery and process time involved in hand held penetrometers for soil compaction measurement. This unit will be very helpful and used for research work to determine the cone index of soil in a fast and effective manner and will help to take sufficient number of data with minimum errors.

D. *Principle of operation*

The penetrometer's cone starts moving towards the soil due to hydraulic force applied by tractor auxiliary hydraulic circuit and the displacement is gauged by the displacement sensor. The load sensor measures the force applied by hydraulic cylinder. The sensor sends the soil resistance force data (Cone Index Data) to the data logger and data will be stored as cone index v/s depth of soil. These data can be processed in computer in the desired format. The penetrometer will be pulled out from the soil by reverse flow of the fluid in the hydraulic cylinder by changing the direction control valve.

Therefore, a first prototype of a tractor operated sensor based soil compaction measurement device has been developed as shown in Fig. 3 and is going through testing phase. Initially, the machine is working at its best and giving the desired results of soil compaction data. Further, a lab model of the same is also under progress so this testing can be done in lab also for further simulation work.

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