ISSN 2229-5518

Modification of Standard Penetration Test System

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Determination of strength of soil is the basic parameter prior to the planning and design of the foundation which is one of the major component of any structure. The Standard Penetration Test is useful for determining the strength of the soil in terms of its bearing Capacity. It also gives the disturbed sample of soil which may be used to examine the soil type and its index properties such as water content, specific gravity, etc. The Current method have certain drawbacks which affect the results and ultimately the value of true bearing capacity of soil. The article deals with the study of drawbacks of the current method of the test and the study of alternatives to enhance the safety and accuracy of the test. Further a complete structural design of test components with estimation and costing is studied.

Keywords: Standard Penetration Test, Soil strength and other parameters, Automation

SPT method consists of split-barrel sampler to obtain the resistance of soil to penetration (N-value) by the impact of 63.5 kg hammer falling from 75 cm height; and to obtain representative samples for identification and laboratory tests.

As it is simple and economic, it is the most widely used soil test to provide an indication of the relative density of all soil types. Although the soil strength parameters which can be inferred are approximate, give a useful guide in ground conditions where it may not be possible to obtain borehole samples of adequate quality like gravels, sands, silts, clay containing sand or gravel and weak rock. The usefulness of SPT results depend on the soil type. It gives the most useful results for fine-grained sands and reasonably useful results for coarser sands and silty sands. It shall be noted that SPT results for clays and gravelly soils are poor representative of the true soil conditions.

The current procedure to carry out the test though simple is very burdensome having following limitations.

1. Tripod above 3m height is used for carrying out the test which is unstable & may tilt while performing the test.

2. Hammer size is very small relative to its large weight of 63.5 kg. This leads to difficult handling and hauling even by two labors.

3. In the existing system the weight is lifted by labors & so free fall of exact 75 cm is not maintained every time which cause inaccurate transfer of energy.

4. If it is lifted less than 75 cm then there will be less energy transfer. In this case the N value will be more which interpretes higher strength of soil than actual.

5. If the weight is lifted more than 75 cm which happens due to inaccurate labor oriented procedure, upward jerk may sometimes take place, lifting the split spoon sampler upward. This is not desirable as it will affect the N value and hence the misinterpretation of soil strength.

6. The test requires 5-7 labors for carrying out the whole SPT test. Also the removal of sampler form soil is a tedious job.

Proposed modified system consists of safety hammer redesigned for easy handling. The hammer is lifted by D.C. motor to minimize the efforts of the labors. The free fall of the hammer is maintained by the use of proximity sensor. The tripod is replaced by tetra-pod for extra stability of the setup.

Clutching & declutching system is adopted to have exact free fall of 75 cm. The equipment is easy to join & dismantle.

Proposed modified SPT system:-

1. Tetra-pod:- In order to achieve lesser height of SPT system, modified safety hammer is used resulting in 2.5m height of the tetra-pod which is considerably less than the tripod. Height of Tetra-pod (when hammer is lifted) = Height of Sampler + Height of Connecting Rod + Lift of 75cm + Clearance with depth of upper disc of hammer.

= 72 + 83+ 75 + 5.5 + 10 = 245.5 cm

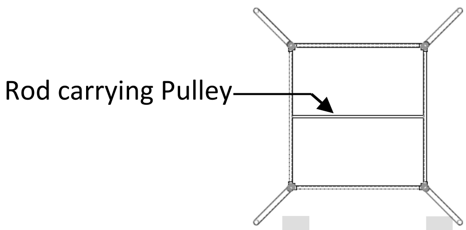


Fig.1a Plan of Tetra-pod

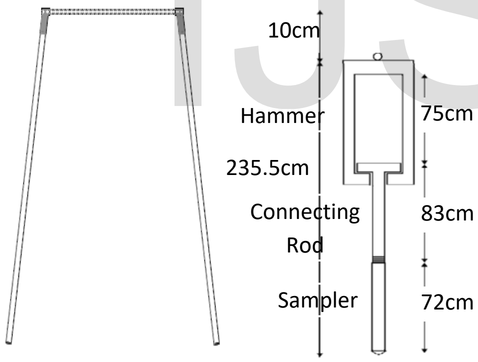


Fig.1b Elevation of Tetra-pod

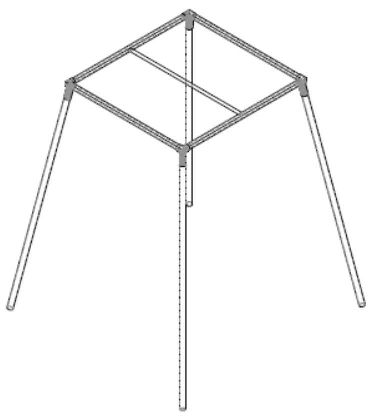


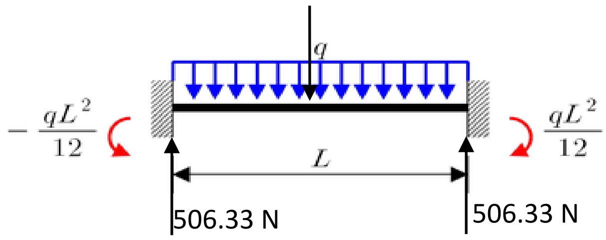
Fig.1c Isometric View of Tetra-pod

Tetra-pod member design:

1.1 Rod carrying pulley:

Solid circular section

Length =1.2 m 944.70N



P = weight of hammer to be lifted + weight of pulley

= 63.5 kg + 0.7 kg

= 64.2 kg

P (factored) = 64.2 × 1.5

= 96.3kg

= 96.3 × 9.81 N= 944.70 N

UDL[1] = Weight of rod[2]/ Length of rod

= 4.62 / 1.2 (kg/m)

= 3.85 (kg/m)

= 3.85 × 9.81 (N/m)= 37.76 (N/m)

UDL (factored) = 37.76 × 1.5

= 56.64 N/m

Max. Moment at mid span:

M = (506.33×0.6) – (56.64×0.6×0.6/2)

= 293.6 N.m

Torsion (factored) = $\text{Weight}_{\text{FACTORED}}$ × Radius of pulley

= 944.70 × 0.05 N.m

= 47.24 N.m

$$R = M + \sqrt{M^2 + T^2}$$

$$= 239.6 + \sqrt{239.6^2 + 47.24^2}$$

= 590.97 (N.m)

Now,

$$\frac{M}{I} = \frac{\sigma}{y}$$

1: Uniformly Distributed Load 2: Rod diameter=25mm; material=MS; Density= 7850 kg/m^3

$$\frac{590.97 \times 10^3}{I} = \frac{230}{y}$$

1: Uniformly Distributed Load 2: Rod diameter=25mm; material=MS; Density= 7850 kg/m^3

ISSN 2229-5518

σ = yield stress =230 N/ mm^2

$$\frac{I}{y} = \frac{590.97 \times 10^3}{230}$$

=2565.22 mm^3

for solid circular section

$$\frac{I}{y} = \frac{\pi d^3}{16} = 2565.22$$

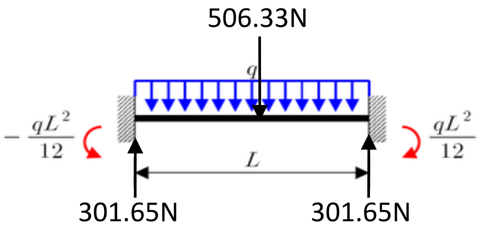
Thus,

d= 23.55 mm < $d_{PROVIDED}$ = 25 mm.

1.2 Adjacent Rods:

Hollow square section-

Length = 1.2m



UDL[1]= Weight of rod[2] / Length of rod

= 6.59 / 1.2

= 5.49 (kg/m)

= 53.87 (N/m)

$UDL_{FACTORED}$=53.87 × 1.5

=80.80 (N/m)

Max moment at mid span:

M_{max}= (301.65 × 0.6) – (80.80 × 0.6 ×0.6/2)

= 166.45 N.m

Now,

$$\frac{M}{I} = \frac{\sigma}{y}$$

$$\frac{166.45 \times 10^3}{I} = \frac{230}{y}$$

$$\frac{I}{y} = \frac{166.45 \times 10^3}{230}$$

= 723.68 mm^3

I/y = (BD^3/12) – (bd^3/12)

B=D=30mm

B=d=20mm

Thus,

I/y = [(30^4/12) – (20^4/12)] / 15

as, y = 15mm

= 3611 mm^3> I/y_{req} =723.68mm^3

So considered section is Safe

1.3 Leg Design:

Slenderness ratio= $\frac{d}{T} = \frac{30}{5}$ = 6 < 15.7

Hence section is not slender.

$$\text{Area} = \frac{\pi*45^2}{4} - \frac{\pi*40^2}{4} = 333.79 \text{ mm}^2$$

$$I_{zz} = = \frac{\pi*45^4}{64} - \frac{\pi*40^4}{64} = 75625.25 \text{ mm}^4$$

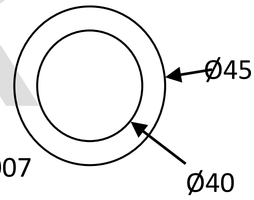
$$\text{Radius of gyration} = \sqrt{\frac{I}{A}} = 15.05 \text{ m}$$

Buckling class = c

One end fixed & one end roller

Effective length = L_e = 1.2 L = 1.2 × 2000 = 2400 mm

$$\lambda = \frac{L_e}{r_y} = \frac{2400}{15.05} = 159.45$$



from table 9(a), IS 800:2007

Fy= 230 MPa ; λ = 159.45

F_{cd} = 68.2 N/mm^2

Design strength = 333.79 × 68.2 = 22.76 KN

Required strength = 0.724 KN

Hence section is safe.

2. Modified hammer:-

Fig.2 Existing hammer

1: Uniformly Distributed Load 2: Rod diameter=25mm; material=MS; Density= 7850 kg/m^3

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Hammer is so reshaped that the height of tetra-pod is resulted 2 feet lesser than the tripod without any change in the weight.

Weight calculation of the modified hammer is as follow:

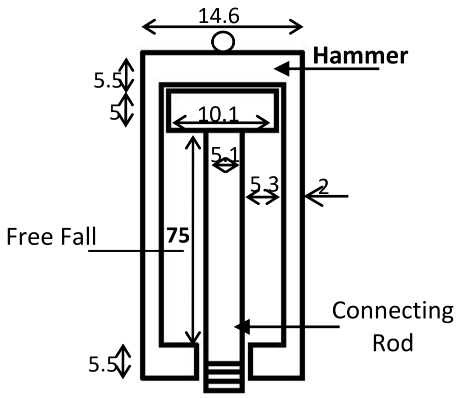

Fig.3 Proposed Hammer

All Dim. in cm (Not to the scale)

Volume 1: (upper solid disc)

$(\pi/4) \times (14.6)^2 \times (5.5) = 920.32\ cm^3$

Volume 2: (middle hollow cylinder)

$(\pi/4) \times (14.6^2 - 10.6^2) \times 80 = 6330.24\ cm^3$

Volume 3: (bottom solid disc)

$(\pi/4) \times (14.6^2 - 5.6^2) \times 5.5 = 784.916\ cm^3$

Total Volume= 920.32 + 6330.24 + 784.916 = $8035.516\ cm^3$

- Density of Mild Steel = 7850 kg /cu.m
- Weight of hammer = Volume * Density
  $= 8035.316 \times (7850 \times 10^{-6})$ kg
  = 63.08 kg

Weight of hook at top= 0.5 kg

Total weight= 63.5 kg

3. Proposed Connecting Rod:

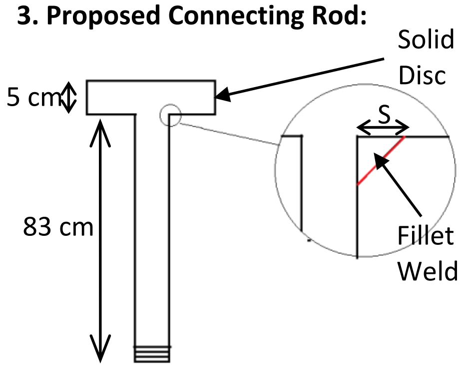

Fig.4 Proposed Connecting Rod

Connecting rod connects the hammer to the sampler. It receives the impact energy from the hammer and transfers it to the sampler safely for its penetration in the soil. It is basically used to protect the sampler from the heavy impact force. The connecting rod is designed for the impact load of 63.5 kg weight through 75 cm free fall.

Weld strength of the fillet weld*:

Conversion of impact energy into static force:

Strain Energy

$$U_m = \frac{5P_m{}^2L}{16AE}$$

Thus,

$$P_m = \sqrt{\frac{16U_mAE}{5L}}$$

$$\sigma_m = \frac{P_m}{A} = \sqrt{\frac{16U_mE}{5AL}}$$

Where, A= area of the disc = $\frac{\pi}{4}D_d{}^2$

L = length of the disc (disc being the susceptible member)

U_m=Strain energy for free fall = mgh

Where, m= mass of body falling freely

g =acceleration due to gravity

h= height of free fall

Thus,

$$\sigma_m = \sqrt{\frac{16 * 63.5 * 9.81 * 750 * 200 * 10^3}{5 * \frac{\pi}{4} 910^2 * 55}}$$

$\sigma_m = 91.45\ N/mm^2$

Design strength of the weld = 915 N/mm^2

$$\text{Design strength of weld } (P_d) = \frac{L_w\, t_e\, f_u}{\sqrt{3} * \gamma_m}$$

$$P_d = 91.45 * A = \frac{\pi D * t_e * 410}{\sqrt{3} * 1.25}$$

Where, (D = 51mm)

$$A = \frac{\pi D_d{}^2}{4} = \frac{\pi\ 91^2}{4} = 6500.58\ mm^2$$

* : Reference- Page No.-693. Mechanics of Material by Ferdinand P Beer, E Russel Johnston Jr, John T Dewolf

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Thus, $t_e = 19.49$ mm

$t_e = k\,s$

$k = 0.7$

$\therefore s = 28$ mm

Provide s = 30 mm

4. Proposed System to maintain the sampler vertical:

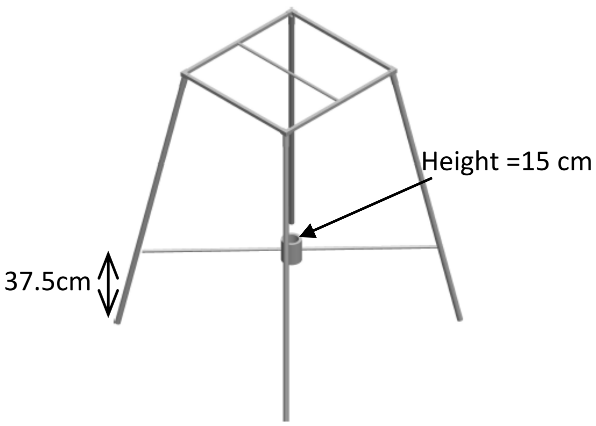

Fig.5 System to maintain the sampler vertical

-The system consists of two 100 cm long plates of thickness 5 mm which hold a hollow cylinder of inner diameter 5.6 cm and outer diameter 10.6 cm.

-The cylinder holds the sampler straight.

-The straightness of sampler gives exact penetration value i.e. N value.

-The system is at 30 cm above ground as shown in Fig. 5

5. Use of DC Motor:

In order to minimize the labor work and to bring easiness in the test, the motor of appropriate configuration can be a good option.

Torque calculation:

Torque = force × moment arm

$= (63.5 \times 9.81) \times 20 \times 10^{-3} \times 1.5$ Nm

(shaft diameter = 40 mm)

$= 18.75$ N.m

Providing , Torque = 20 N.m

Power = torque × angular velocity

$$= 20 * \frac{2\pi N}{60}$$

(N = 30 rpm)

Power = 62.83 Watt

Providing, Power = 90 Watt

Adopted configuration of the DC motor:

Table 1 Motor Specification

Power	0.12 Hp= 90Watt
Torque	200 kg.cm
Rpm at the Shaft	30

6. Use of proximity sensor:

The proximity sensor having sensing limit of 8 mm is used to maintain free fall of exact 75 cm. It is fixed on hammer as shown in Fig.6. Distance between sensor and connecting rod is 20 mm thus it will not sense the connecting rod & will not send any signal. As the motor lifts the hammer, the sensor fitted on the hammer moves upward.

When the sensor reaches 75 cm it senses the connecting rod (point A) which is now 2 mm from it & alarms, at which a clutch is applied to disconnect the hammer from motor shaft maintaining the free fall of exact 75 cm.

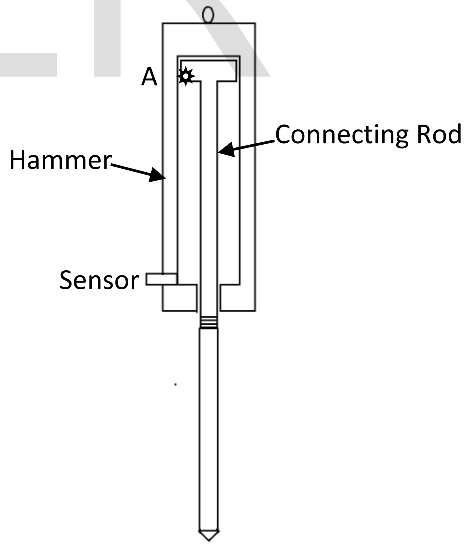

Fig.6 Use of Proximity Sensor

Fig.7 Proximity Sensor

7. Other Components:

7.1 Pulley:

Outer diameter = 50 mm

Inner diameter = 25 mm

Thickness = 10mm

7.2 Rope:

5 mm thick rope is used.

7.3 Battery:

Calculation:

Power / power ratio = V × A

Power = 46.5 watt

Power ratio = 0.8

So,

V × A = 46.5 / 0.8

Providing, V = 10.5 volt

Thus,

A= 5.56 ampere

So, providing 10.5 volt; 14 A battery

8. Detail Drawings and Connections:-

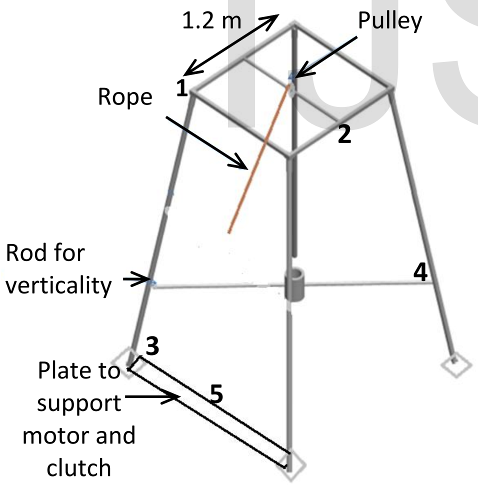

Fig.8 Isometric view of the proposed model

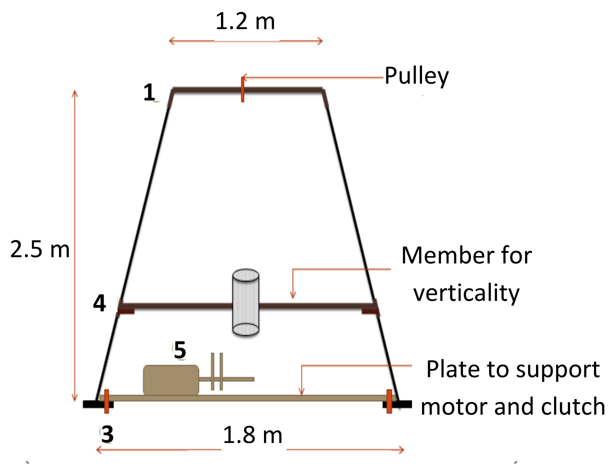

Fig.9 Elevation of the proposed model

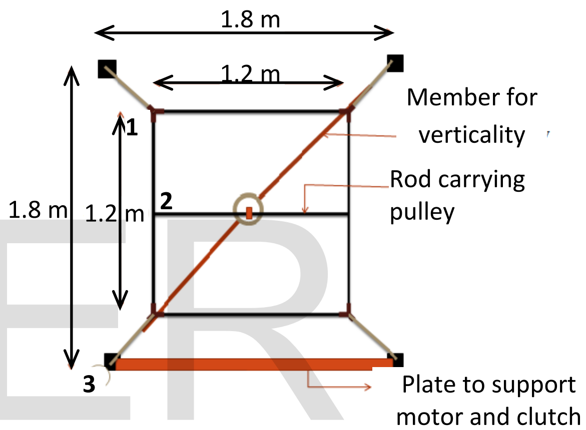

Fig.10 Plan of the Proposed Model

Connection: 1

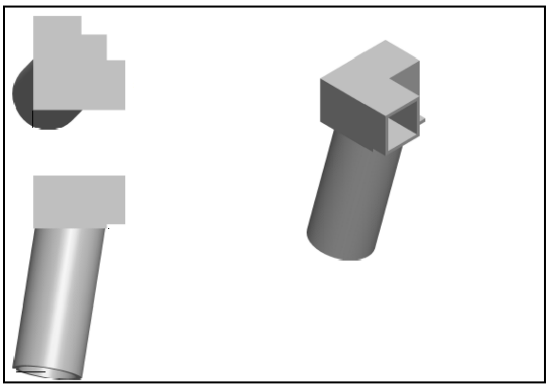

Fig.11 Angle clit used for the connection

Connection: 2

The connection 2 is between rod carrying pulley & the frame.

The two rods are welded together.

Connection: 3

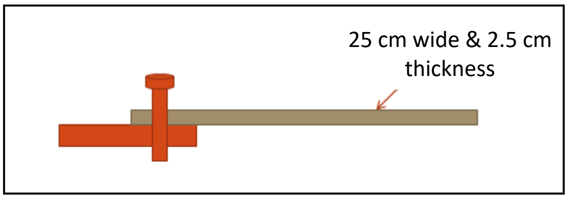

Fig.12 Bolt connection between Leg and Plate carrying Motor & Clutch arrangement

Connection 3 is the connection between the plate supporting & the leg.
The plate is bolted with the plate that is welded to the legs.

Connection: 4

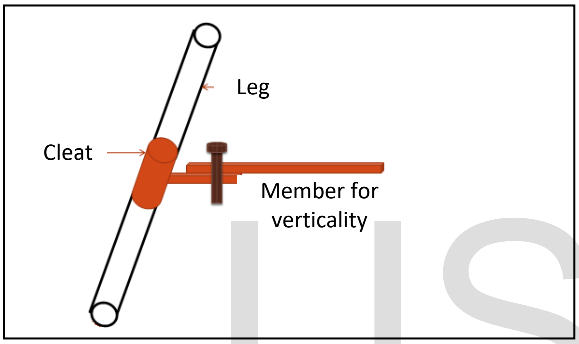

Fig.13 Connection of Leg with Member for Verticality

Connection: 5

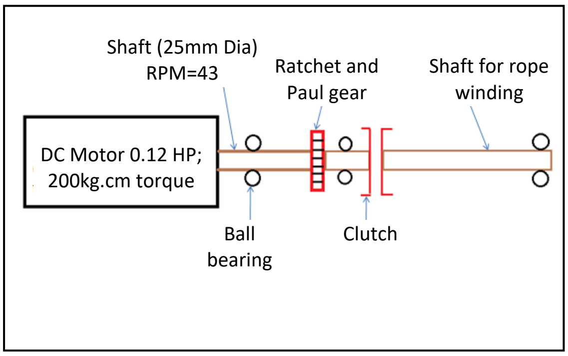

Fig.14 Motor & clutch system

Details of the elements of connection 5 are as follow:

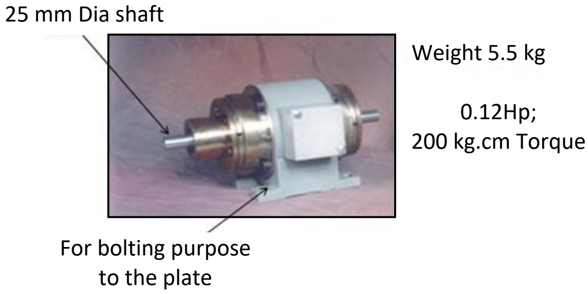

Fig.15 Motor

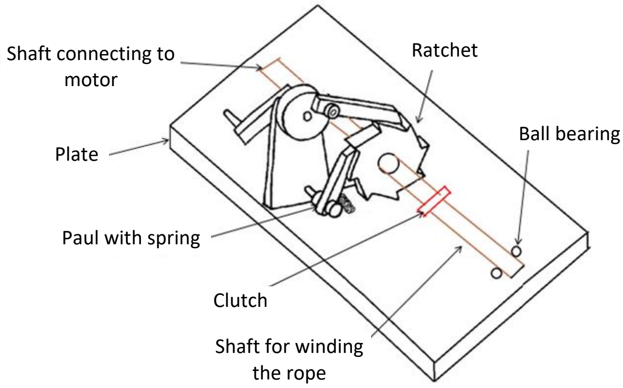

Fig.16 Ratchet and Paul Gear & clutch arrangement

Fig.17 Ratchet & Paul gear

Fig.18 Ball Bearing

9. Working of clutch

As long as two discs not touching, drive disc can spin freely without affecting driven disc. If discs pressed together, spinning drive disc will engage driven disc, two discs will spin together. Spring loaded mechanism connected to clutch pedal used to pull discs together or apart. When clutch pedal on mower released, discs pressed together and clutch engages. When clutch pedal pressed down, discs move away from each other and clutch disengages.

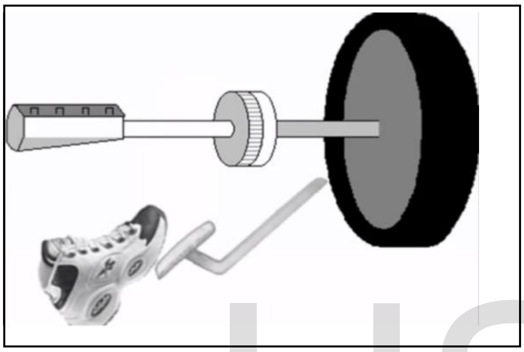

Fig.19(a) Stage-1

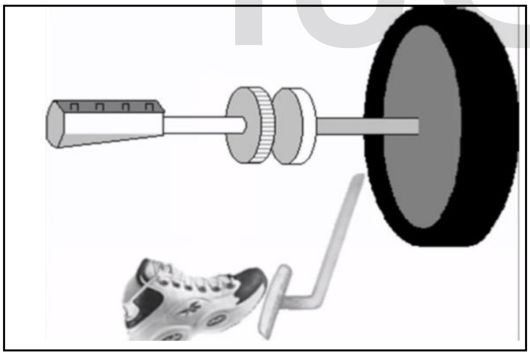

Fig.19(b) Stage-2

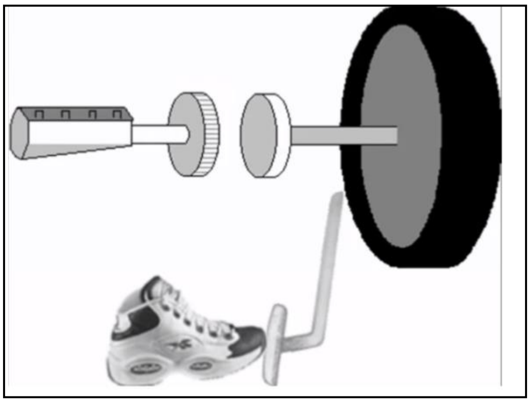

Fig.19(c) Stage-3

10. Removal of sampler &dismantling:

In the current procedure of SPT, the removal of sampler from the ground is found to be very difficult and unsafe.

In suggested model, due consideration is given to this aspect. For removing the sampler the motor is allowed to lift the weight above 75 cm for the depth of penetration. The use of sensor is tuned off, so the motor will not stop and continue to uplift the safety hammer.

11. Cost Analysis

11.1 STEEL

11.1.1 Rod carrying pulley:

Material= MS
Section= Solid circular
Length= 1.2m
Diameter= 25mm
Weight= 4.59kg

11.1.2 Adjacent rods:

Material= MS
Section= Hollow square
Length= 1.2m
Outer side= 30mm
Inner Side= 20mm
Number= 4
Weight of single rod= 4.71kg
Total weight= 18.84kg

11.1.3 Legs:

Material= MS
Section= Hollow circular
Length= 2m
Outer diameter= 30mm
Inner diameter= 20mm
Number= 4
Weight of single leg= 7.85kg
Total weight= 31.4kg

11.1.4 Hammer:

Material= MS
Weight= 63.5kg

11.1.5 Connecting rod:

Material= MS
Weight= 16.15kg
Total weight (Circular) = 115.64kg

Total weight (Square) = 18.84kg

Rate= Rs.56 per kg for circular section
Rate= Rs.60 per kg for square section

Cost= (115.64×56) + (18.84 ×60)
= 6476 + 113
= Rs.7606/-

11.2 Motor with gear box:
Configuration:
Power= 0.12 Hp
Torque= 200 kg.cm
Cost: Rs.6500/-

11.3 Clutch:
Cost = Rs.4500/-

11.4 Sensor:
Configuration
Proximity Distance= 8mm
Cost: Rs.3000/-

11.5 Other & contingencies:
Cost of fabrication: Rs.5000/-
Contingencies: Rs 4000/-

TOTAL COST= Rs. 30000/-

12. Summary:
An attempt is made to eliminate drawbacks of manual laborious method of current standard penetration test by automation of the same.
1. Use of tetra-pod instead of tripod brings more stability to the test.
2. With redesigned shape of hammer, height of the instrument is decreased to 2.5m.
3. Verticality of sampler is given due consideration which brings more accuracy in interpretation of soil strength.
4. With the use of proximity sensor, exact free fall of 75cm is achieved.
5. Use of motor in accordance with clutch and gear system eliminates laborious lifting of 63.5 kg heavy hammer.
6. Further, removal of embedded sampler from the soil is possible without any labor using the motor.
Thus automation of standard penetration test brings safety, accuracy and eliminates labors.

Acknowledgement:
I wish to express my sincere gratitude to my project guide W. S. Marathe (Asst. Prof. of Civil Engineering Department, SSVPS, Dhule) for his kind guidance. I also take this opportunity to thank Dr. K. K. Tripathi (Asst. Prof. of Civil engineering Department, COEP) for his help in various aspects.

REFERENCES:
[1] IS: 2131 – 1981.
[2] IS: 6403 – 1981.
[3] IS 800 : 2007
[4] Gopal Ranjan, A. S. R. Rao, “Basic And Applied Soil Mechanics,” New Age International Publishers, Revised Second Edition, Reprint 2008, pp.485-511, pp.680-683.
[5] B. C. Punmia, “Soil Mechanics & geotechnical engineering,”
[6] Joseph E. Bowles, “Foundation analysis & design”
[7] Ferdinand P Beer, E Russel Johnston, J. Dewolf, “Mechanics of Material”
[8] Subramannyam, “Steel Design”
[9] S. Ramamrutham, “Strength of materials”, Dhanpat Rai Publoishing Company, 13th Edition
[10] M. Sherif Aggour & W. Rose Radding, “Reaserch Report”, September 2001
[11] Department of the Army, U.S. Army Corps of Engineers, Washington, DC 20314-1000, “Engineering and Design, Standard Penetration Test” 1988
[12] Saskatchewan highways and transportation, “Standard test Manual procedures”