LWD and DCP

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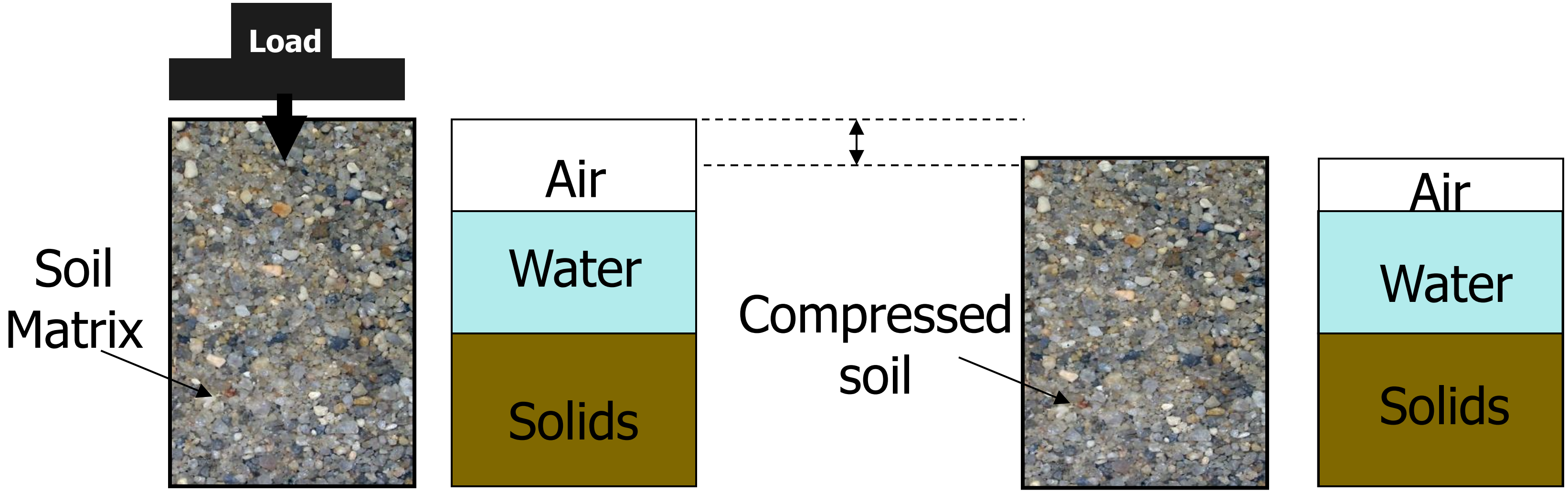
Definition:

Compaction of soil by removing air voids using mechanical equipment.

Usually no change in water content during compaction.



Soil Compaction

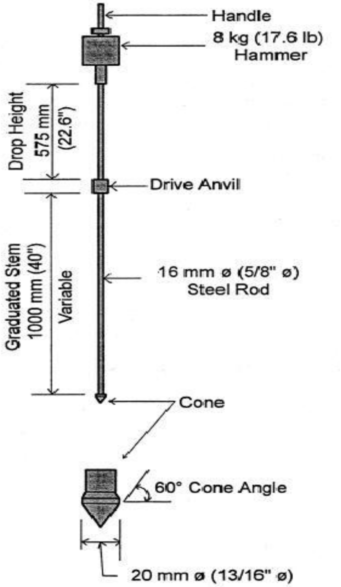
Objectives of Compaction:

- Increasing the strength of embankment;
- Decreasing the settlement of pavement;
- Control undesirable volume changes;
- Reduction in hydraulic conductivity;
- Increasing the stability of slopes.
- Reduce the erosion damage.

Devices Used for Compaction Testing

Light Weight Deflectometer

Dynamic Cone Penetrometer



Nuclear Gauge

Sand Cone

Compaction equipments

Rammer

Sheep Foot Roller

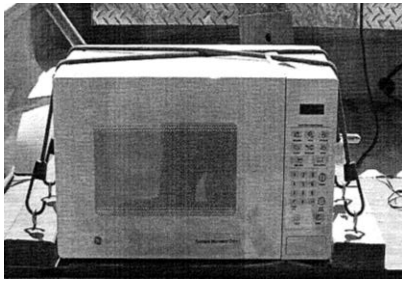
Plate Vibratory Roller

Vibratory Roller

Approved Moisture Test Methods

Field Moisture Test (ITM 506)

Microwave moisture:
Microwave with 700 watts input power, G-2 balance, samples size 100 gm, and test duration 5 minutes.



Stove /or Hot plate:
Stove, G-20 or G-2 balance, samples size 1000g/or 500g and test duration 25 minutes.

Moisture probe:
Campbell moisture probe, Proctor mold, rammer, G -20 balance, sample size 3000g, and test duration 25 minutes.

INDOT Compaction Requirements

Density based Earth Work Specifications:

Clay -- 95% of Max Density within of -2 to +1 of OMC
Silt -- 95% of Max Density within of -3 to OMC
Sand -- Several points below the OMC

Lab Testing:

Moisture -- Density Relation-Std. Proctor (AASHTO T-99)
Moisture -- Density Relation-Modified Proctor (AASHTO T-180) for Railroad embankment

Field Testing: Nuclear Gauge, Sand Cone, Moisture Test by Stove Top & Microwave, and One-Point Proctor Test

Moisture Density Curve:

Y:\Div.material& Test\Moisture Density Curve

Motivation Behind The Change

- Measure fundamental properties of material (strength, modulus, CBR),
- Identify the poor and good compaction in short time,
- Simple enough to train and easy to perform with no electronics
- Precise enough to accept with confidence,
- Safety issues (management of nuclear gauges)

Compaction Related Research Projects

JTRP & In-house Research

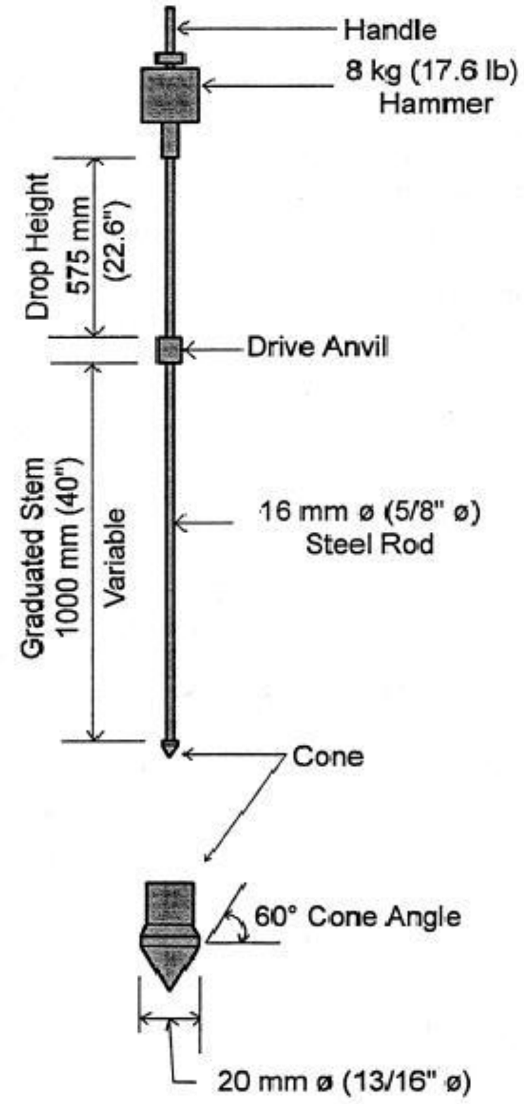
1998, JTRP Technical Report Series
Cone Penetration Test to Assess the Mechanical Properties of Subgrade Soils

2010, FHWA/IN/JTRP-2010/27 SPR- 3009
Use of Dynamic Cone Penetration And Clegg Hammer Tests For Quality Control of Roadway Compaction and Construction,

SPR-3635: QA/QC of Subgrade and Embankment Construction-Technology Replacement and Updated Procedures

SPR 3651 : Developing Statistical Limits for Using the Light Weight Deflectometer, LWD, in Construction Quality Assurance

DCP – Dynamic Cone Penetrometer



Dynamic Cone Penetrometer (DCP)

Lab Criteria for DCP Blow Counts
The following lab tests are required:

- Sieve Analysis………………….AASHTO T-88, T-89,/or ASTM D-1140
- Atterberg Limits ……………….AASHTO T-90
- Moisture –Density ………… AASHTO T-99
- Loss on Ignition………………. AASHTO T-267
- Ca/Mg Carbonate…………….ITM-507

A representative soils sample (25 lbs) from project limit or borrow pit:

Dynamic Cone Penetrometer (DCP)

Field Test for DCP Blow Counts

- One Point Proctor for Cohesive Soils……..ITM 512
- Dynamic Cone Penetrometer………………..ITM 509
- Field Determination of Moisture Content of Soils……………ITM 506

Soil Classification for Compaction

Cohesive soils: Soils should be 35% or more passing 200 sieve.

This classification is based on **density** and **behavior** of soils.

- **Clayey Soils**: Soils with a maximum dry density of **112** pcf or less
- **Silty Soils**: Soils with a maximum dry density greater than **112** pcf and less than or equal **120** pcf.
- **Sandy Soils**: Soils with a maximum dry density greater than **120** pcf.

Note: There are few exceptions such as Loess (wind blown silt, dune sand) or soils blended with recycled materials.

Soils Classifications

Example of INDOT Laboratory Soil Classifications									
Soil Type	#10 % Passing	#40 % Passing	#200 % Passing	LL	PL	PI	Max Wet Density (Pcf)	Max Dry Density (Pcf)	OMC (%)
Silty Loam	90	57	65	0	0	0	127	114	11
"	93	65	59	0	0	0	130	116	12
"	94	65	60	0	0	0	129	115	12
"	97	58	56	0	0	0	132	117	13

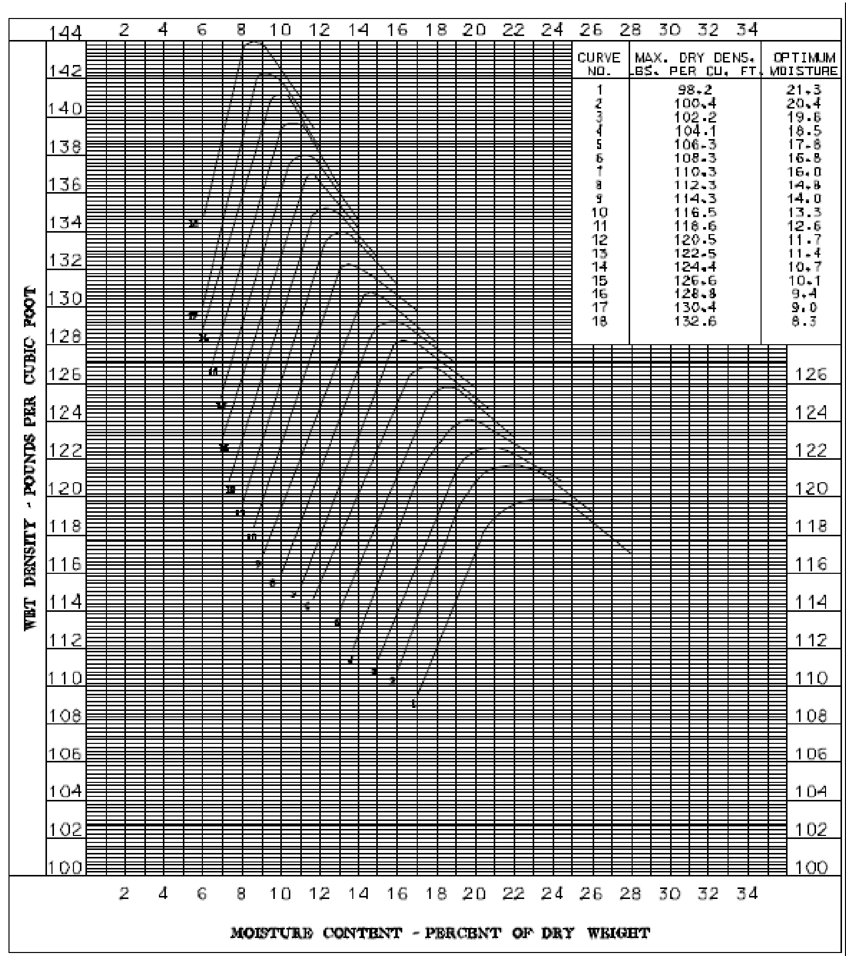
DCP blow counts of 12 per 2- 6 inches lifts for silty soils with four different OMC

Moisture Content Density Curve

These curves are <u>NOT</u> to be used with <u>Granular</u> Materials.

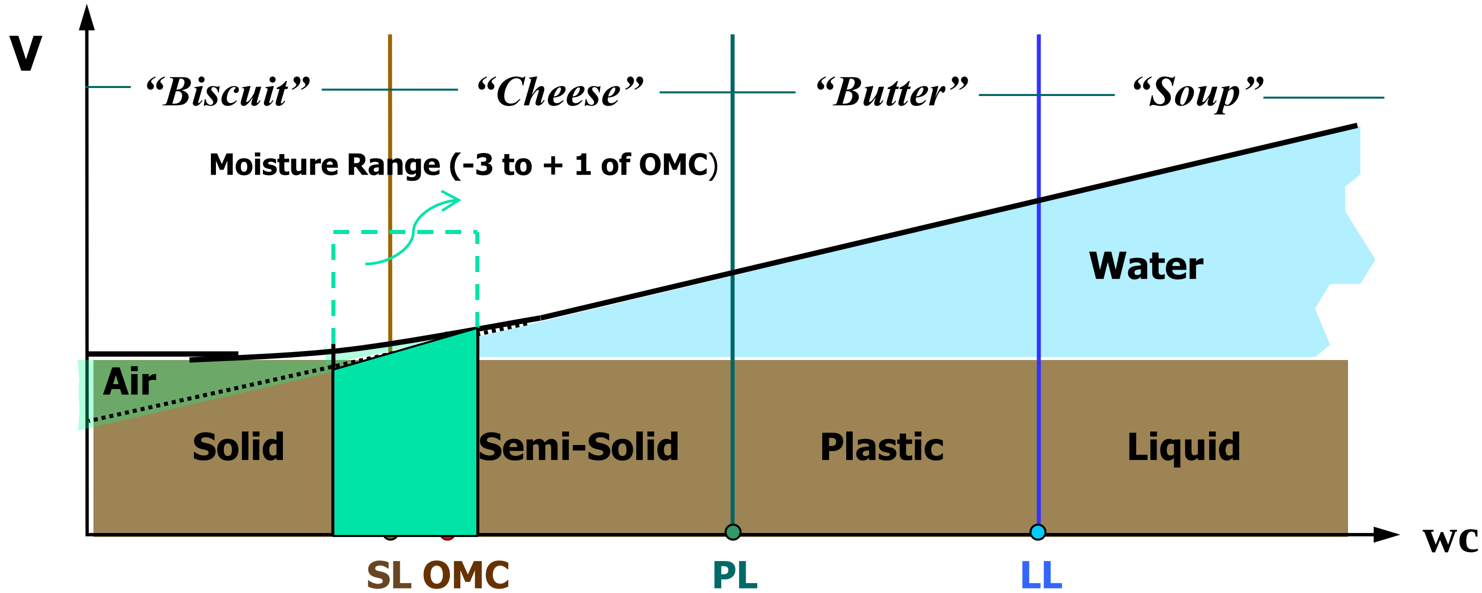
(Curves based on data acquired from July 1965 to January 1963 by Soils Dept.)

Typical Moisture Density Curves
Division of Materials & Tests
Indiana Department of Transportation



CURVE NO.	MAX. DRY DENS. LBS. PER CU. FT.	OPTIMUM MOISTURE
1	98.2	21.3
2	100.4	20.4
3	102.2	19.6
4	104.1	18.5
5	106.3	17.8
6	108.3	16.8
7	110.3	16.0
8	112.3	14.8
9	114.3	14.0
10	116.5	13.3
11	118.6	12.6
12	120.5	11.7
13	122.5	11.4
14	124.4	10.7
15	126.6	10.1
16	128.8	9.4
17	130.4	9.0
18	132.6	8.3

Correlation between Plastic Limits
Optimum Moisture Content for Cohesive Soils



(after Jumikis (1962), Paek, (2006))

- **OMC should be smaller than Plastic Limit (PL)**

Soil above the plastic limit

Hand Cast Test:

Determined Moisture Content by hand cast.

Soil cast approx:
3% below OMC

Barely held together

Easily broken under minimal pressure.

One Point Proctor Apparatus

Proctor Mold

Scoop

Metal Rammer

Straightedge

Sample Ejector (Optional)

No.4 Sieve

Trowel

One Point Proctor Compaction

Place the mold on a hard stable surface

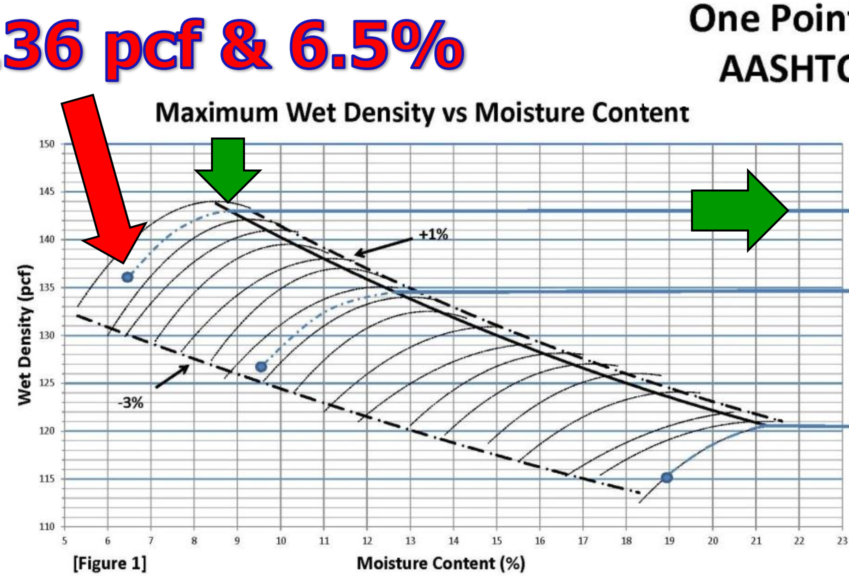
Place the passing #4 material in three equal layers

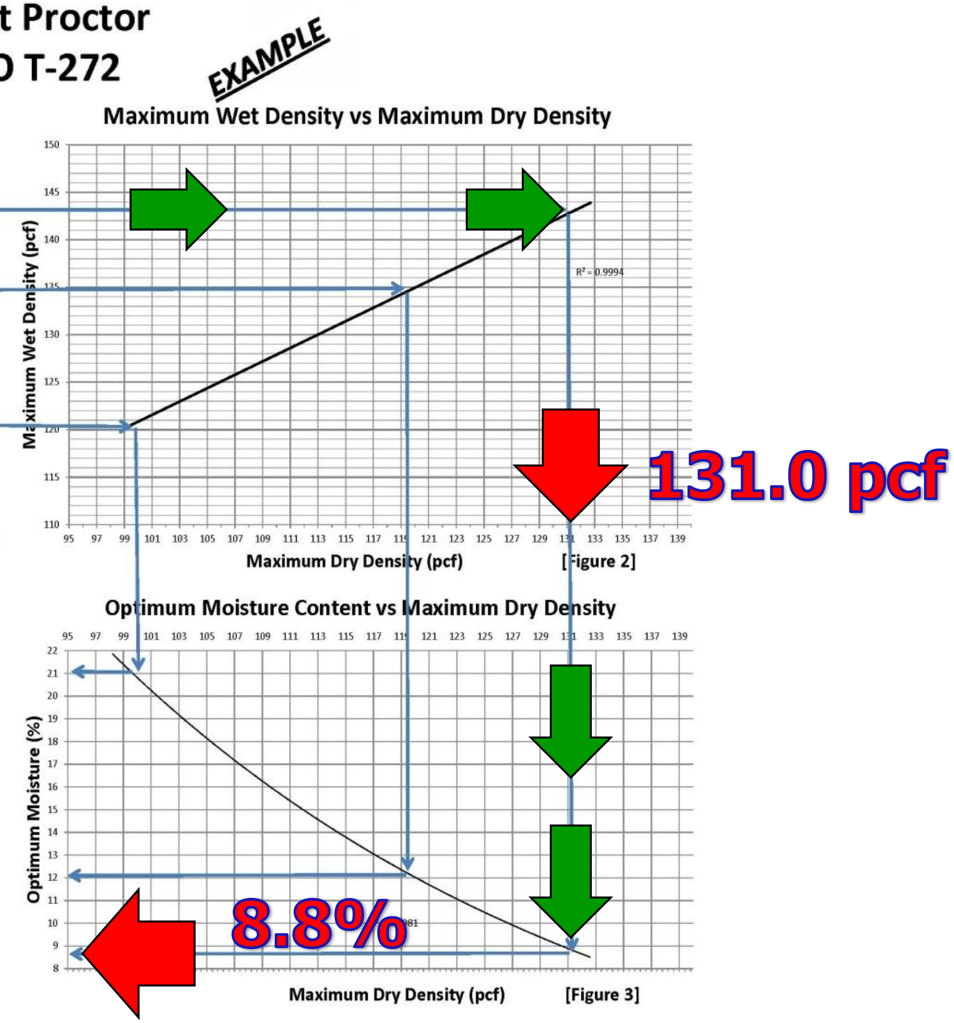
Compact each layer 25 times with the hand hammer-5.5 lbs. dropped 12 inches

Dynamic Cone Penetrometer

Field Criteria for DCP Blow Counts

One Point Proctor
AASHTO T-272





- Data not to be used with Granular Soils.

-Plot based on data acquired from July 1965 to January 1969 by Soils Department.

-Moisture must be between -3% and +1% for a valid Maximum Wet Density.

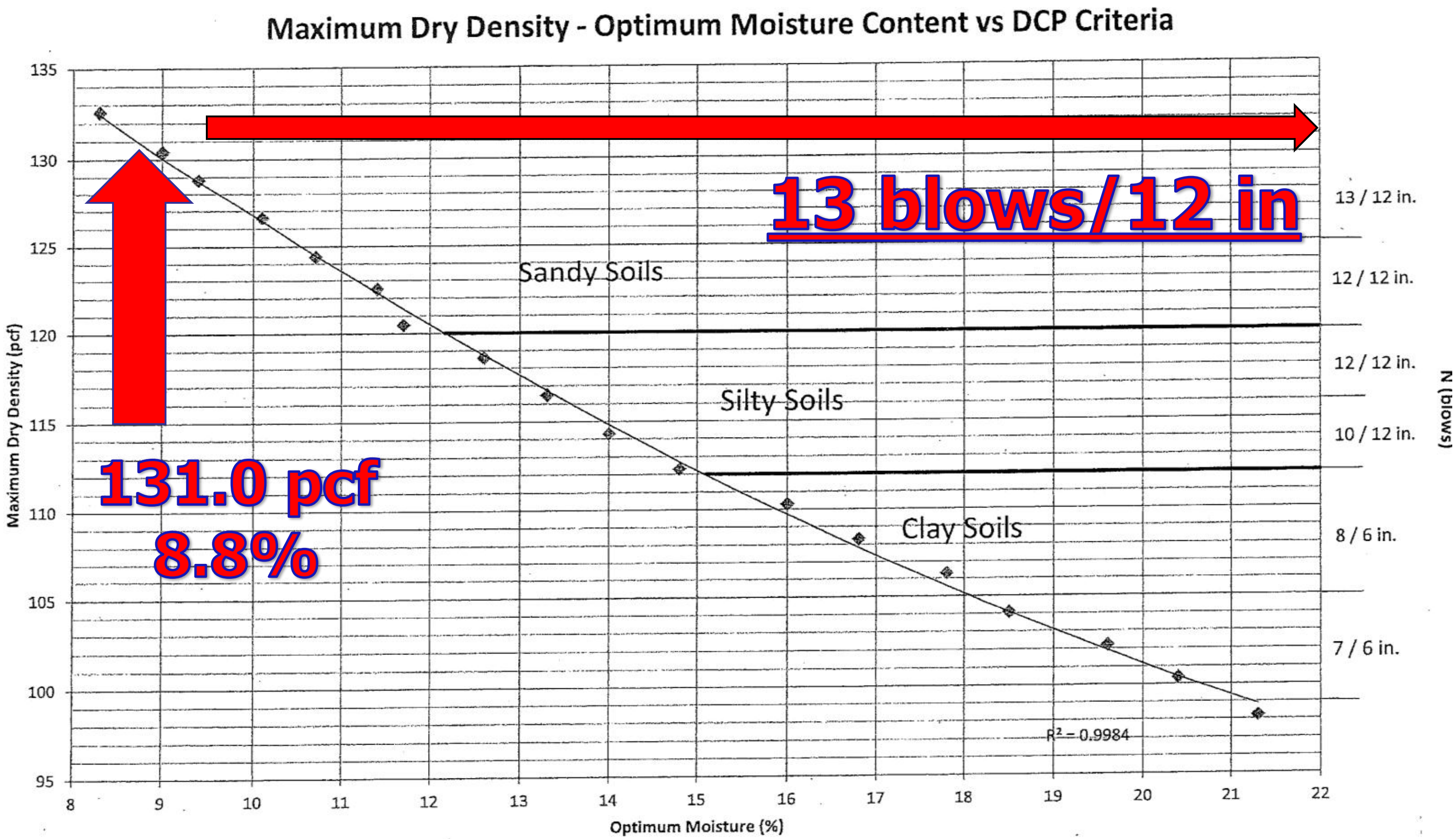
-These charts are an alternative to the Family of curves and may be used in accordance with AASHTO T-272.

-Revised 1/18/13

M:\DTE-ME\Soils\Moisture Density Curves 2D.pdf

Dynamic Cone Penetrometer (DCP)

Field Criteria for DCP Blow Counts
Maximum Dry Density-Optimum Moisture Content Vs DCP Criteria



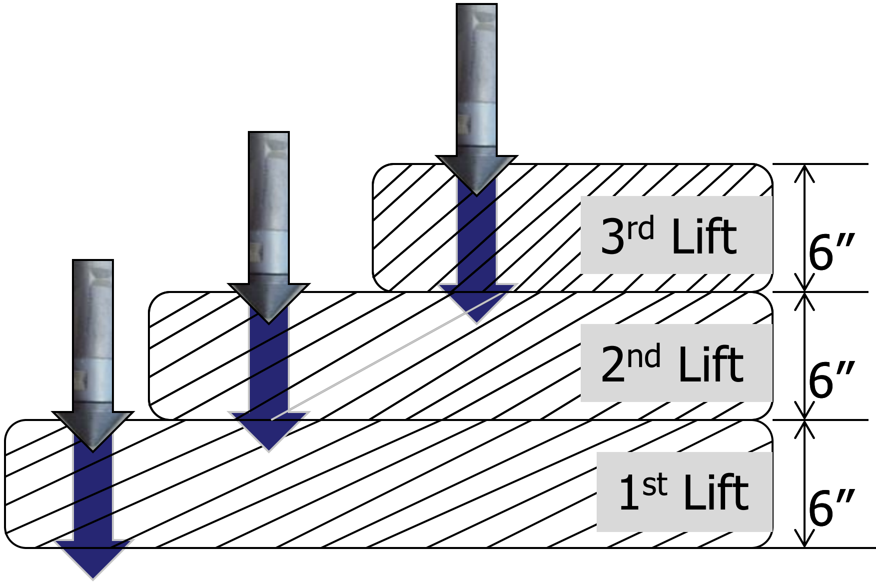
DCP Criteria for Compaction

Plastic Index , Max. Dry Density VS DCP blows Relation

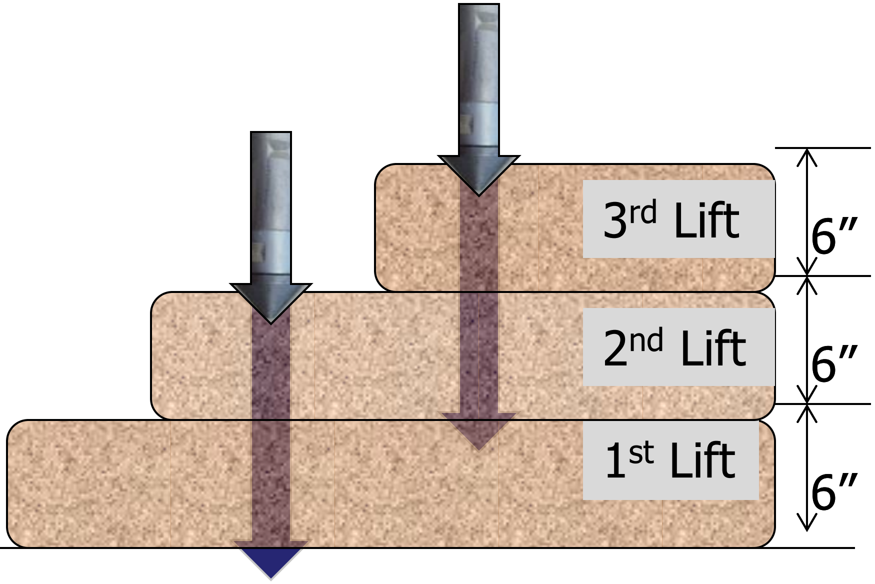
S.No	Textural Classification	Plastic Index	Max. Dry Density pcf	DCP criteria for 6 in. lift	DCP criteria for 12 in. thick (2 lift of 6 in.) (95 % Compaction)	DCP Criteria for 0 to 12 in. thick (100% Compaction)
A	**Clay Soils**					
	Clay Soils	greater than 20	less than 105 pcf	7		
	Clay Soils	8 to 20	105 to 112 pcf	8		
B	**Silty Soils**					
	Silty Soils	4 to 8	113 to 116 pcf		10	
	Silty Soils	less than 4	117 to 120 pcf		12	
C	**Sandy Soils**					
	Sandy Soils	less than 8	121 to 125 pcf		12	
	Sandy Soils	less than 4	greater than 125 pcf		13	
D	**Granular Soils**					
	Structure Backfill					
	Structure backfill # 30				7	10
	Structure backfill # 4				10	12
	Structure backfill # 1/2 in.				12	14
	Structure backfill # 1 in.				18	-

Dynamic Cone Penetrometer (DCP)

Dynamic Cone Penetrometer Testing of Cohesive and Granular Soils



Clayey Soils



Silty, Sandy and Granular Soils

Dynamic Cone Penetrometer (DCP)

Moisture Requirements with Dynamic Cone Test

Silty and sandy soils: -3% points and the OMC
Clayey soils: -2% points and +2% points OMC
Granular soils: -6% points and the OMC (b-borrow, Str. backfill)

Moisture will be determined by ITM 506 (Stove top, microwave, or Campbell moisture probe)

OMC for Granular Soils will be determined by AASHTO T-99 and OMC for Silty, Sandy, and Clayey Soils will be determined by One Point Proctor (INDOT Family Of Curve)

Compaction Recommendations

Clays- Sheep Foot Rollers

- Most effective for cohesive or plastic soils
- Four to Eight passes
- Sheep foot roller can be effective in reducing open spaces between clay chunks at moisture over the plastic limit of the material.
- When clay chunks are too stiff (moisture is less than optimum), compaction would not close spaces between clay chunk and settlement may occur later.
- Compaction too wet would result into consolidation and settlement.

Silty, Sandy Material- Pneumatic Tired Rollers

- Most effective for low plastic clayey and silty soils.
- Moisture is critical for these soils and it should below the optimum moisture content.

Compaction Recommendations

Granular Soils – Vibratory Compactor

- Equipments should vibrate at the frequency closed to the resonant frequency of material.

- Frequency (High to Low) and low aptitude set the particles in motion and rearrange the particles into denser state.

- Moisture reduces the inter particle friction (Granular soils not sensitive to moisture).
- Granular soils compaction (Strength) is affected by the confinement.

- Additional roller passes (more efforts) may cause loosness of the compacted mass.
- In confined areas, lift thickness should be reduced to 4 inches and compacted with power rammer or vibratory plate.

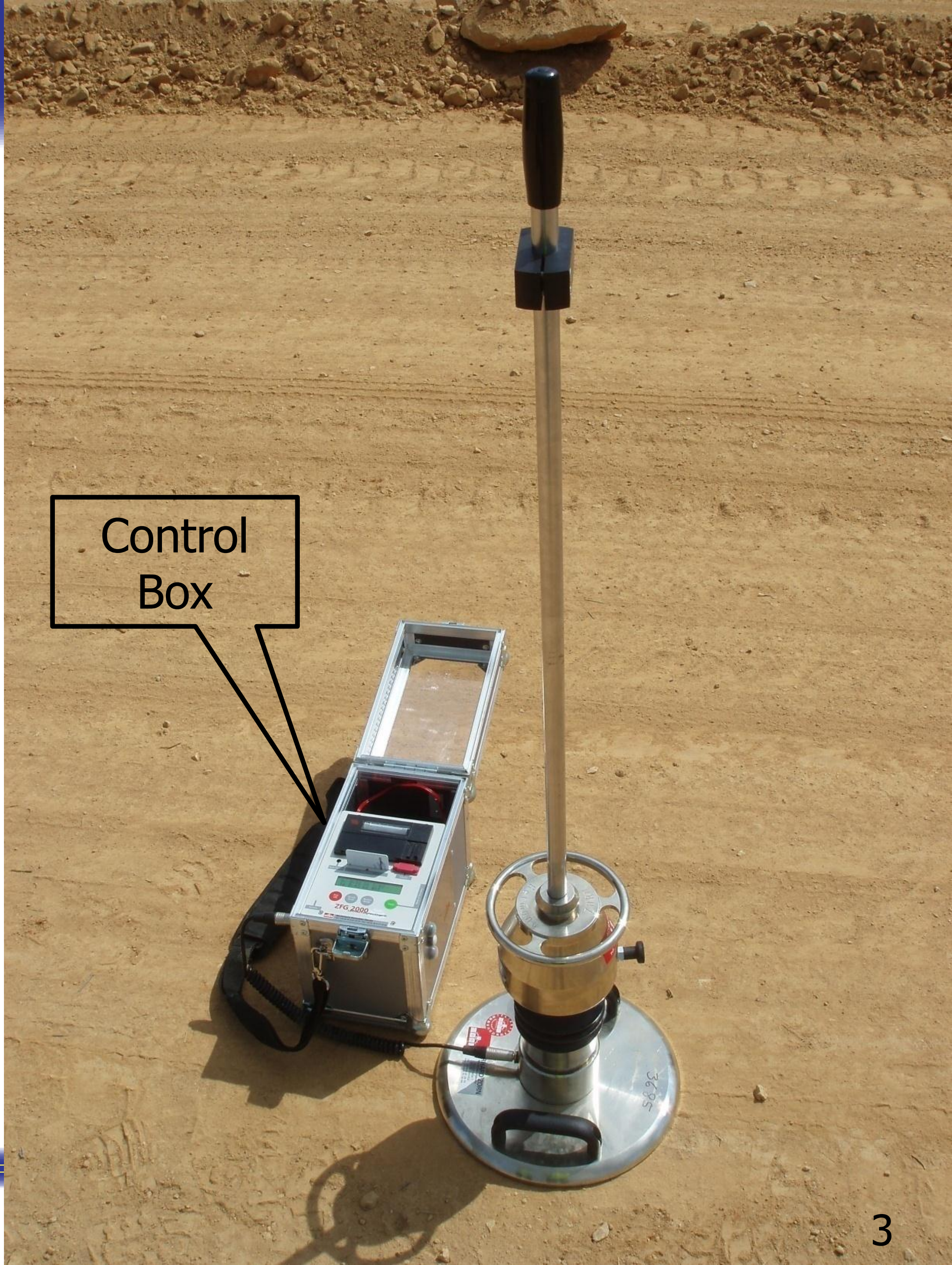
Subgrade Proof Rolling

LWD – Light Weight Deflectometer

ITM 508

ASTM E 2583- 07

ZORN model ONLY



LWD Test Pad Construction

LWD

Overview

Light Weight Deflectometer (LWD)

- LWD is device that measure the deflection from a falling weight and estimate the modulus.
- The LWD shall have one accelerometer below the fall weight hammer.
- The grade shall be proofrolled prior to placing of aggregates.

Equipment Listing:

- **Handle grip:** is located at the top of the device. It is used to hold the LWD guide rod plumb and to limit the upward movement of the falling weight.
- **Top fix and release mechanism:** holds the falling weight at a constant height.
- **Guide Rod:** allows the falling to drop freely.
- **22 lb. Falling Weight:** is manually raised to the bottom of the grip and held into place using top fix/release mechanism,
- **Lock pin:** has two positions (locked and unlocked),
- **Steel rings:** provide a buffer system that transmits the load pulse to the plate resting on the material to be tested.
- **12 in. Loading plate:** Provides an approximate uniform distribution of the impulse load to surface.

LWD Testing Procedure

- Select site and set up LWD connection to its computational unit.
- The test section should be level and smooth.
- Set the plate on a prepared surface and seat it by turning it left and right 45 degrees. Do not drop the loading plate on the prepared surface.
- LWD plate should not translate laterally with each successive drop.
- Perform 3 seating drops before collecting the data. If noticing excessive deflection,
  - Material needs additional compaction,
  - Following the three seating drops, perform three drops from a fixed height.
  - Record the data from each drop and the average of 4th, 5th and 6th drops.

LWD Test

- **Acceptance test for compaction of chemically modified subgrade shall meet the following:**
  - Max. allowable deflection for lime modified subgrade shall be 0.30 mm or less,
  - Max. allowable deflection for cement modified subgrade shall be 0.27 mm or less,

or

Select a test pad 100 feet by 20 feet.

- **Field tests required for the test pad:**
  - Four DCP passing tests shall be performed randomly through out the test pad.
  - DCP tests shall meet the requirement of Sec 215.09.
  - Ten randomly selected LWD tests (deflection).
  - Average deflection from the 10 LWD tests shall be used to perform compaction control.

LWD Test

- **Acceptance test for compaction of aggregate over chemically modified subgrade shall meet the following:**
  - Max. allowable deflection for aggregate over lime modified subgrade shall be 0.30 mm or less,
  - Max. allowable deflection for aggregate over cement modified subgrade shall be 0.27 mm or less,

or

Select a test pad 100 feet by 20 feet.

Construct a test pad in accordance with special provisions

LWD Test

Acceptance Testing

Chemically modified soils ………One test per1400 CYD for two lane road.

Chemically modified soils shall be proofrolled.

Aggregates over chemically modified soils ………One Test for 800 t

Moisture Test …………………………………………….One Moisture Test /day

Conclusions:

- The DCP is portable, easy to operate, and requires no electronics. It is easy to train.
- It is an effective tool to identify weak layers when penetration rates are plotted vs. depth.
- DCP and LWD ranked highest in practicality (NCHRP).
- LWD and DCP are the cheapest in quality control equipments.
- DCP and LWD measured the fundamental properties of the material.
- Acceptance criteria is related to design.
- CBR and resilient modulus values can be reliably predicted using DCP and LWD test results.
- Density is volumetric property while stiffness or modulus is fundamental property of the soil that relates with performance.

Cost Comparison of NDG, DCP, & LWD

Device	Estimated Tests Per 8-hr Day	Daily Employee Rate	Daily Equipment Rate	Daily Charge	Cost Per Test (Approx.)	Est. Device Price
NDG including 1-Point Proctor	18	$336.00	$35.00	$371.00	$20.60	$ 8,000.00- $12,000.00
DCP	32	$336.00	$ 3.00	$339.00	$10.00	$ 1,000.00- $ 1,300.00
LWD	72	$336.00	$14.00	$350.00	$ 5.00	$ 10,000.00- $ 12,000.00

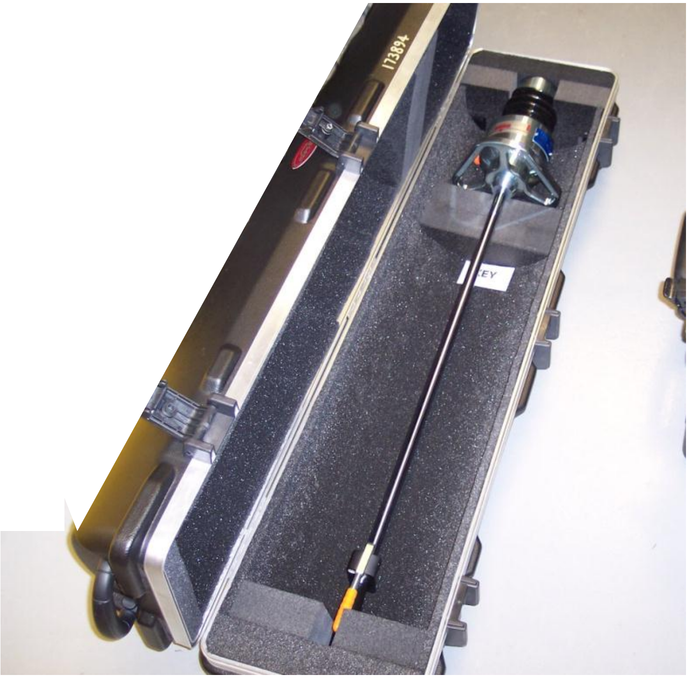
Other Costs:
NDG - Training: Safety and Maintenance
DCP - None
LWD- Calibration and Verification

Compaction Control Using DCP & LWD

Compaction Requirements

Material Types	Lab Testing	Field Testing						
		Maximum Density (AASHTO T-272)	DCP (ITM-509)	Sand Cone (AASHTO T-191)	Nuclear Gauge (AASHTO T-191)	Moisture Test		LWD (ITM-508)
						ITM - 506	AASHTO T-255	
Soil	AASHTO T-99 (Method A)	X	X	X	X	X	N/A	N/A
Soils with aggregate retained on the ¾ in. and Structural Backfill sizes 2 in. and 1 ½ in.	AASHTO T-99 (Method A or C)	N/A	N/A	X	X	X	N/A	X
Soils with 100% passing ¾ in., B-borrow, and Structural Backfill Sizes 1 in., ½ in. No. 4, and No. 30)	AASHTO T-99 (Method A or C)	N/A	X	X	X	X	N/A	N/A
Coarse Aggregates (No. 43, 53 and 73)	AASHTO T-99 (Method A or C)	N/A	N/A	X	X	N/A	X	X
Chemically Modified Soils	AASHTO T-99 Performed by a Contractor	N/A	X	N/A	N/A	X	N/A	X

LWD Case



INDOT Inventory of LWD & DCP

LWD (ZORN) & DCP (KESSLER)		
District	**Total No's of LWD available**	**Total No's of DCP available**
CRAWFORDSVILLE	8	10
FORT WAYNE	8	17
GREENFIELD	11	30
LA PORTE	10	25
SEYMOUR	8	13
VINCENNES	13	20
Office of Geotechnical Services	2	2
Total	**60**	**117**

INDOT Inventory of NDG

Nuclear Density Gauge (Troxler)			
District	**Total Numbers**	**Dispose off**	**Available**
CRAWFORDSVILLE	16	16	-
FORT WAYNE	18	18	-
GREENFIELD	16	16	-
LA PORTE	17	17	-
SEYMOUR	17	17	-
VINCENNES	22	8	14
Total	**106**	**92**	**14**

Nuclear Gauge leaving INDOT facility

ITM's and Important Links

- **ITM-506: Field Moisture Determination**

  http://www.in.gov/indot/div/mt/itm/pubs/506_testing.pdf
- **ITM-508: Field Determination of Deflection Using Light Weight Deflectometer**

  http://www.in.gov/indot/div/mt/itm/pubs/508_testing.pdf
- **ITM-509: Field Determination of Strength Using Dynamic Cone Penetrometer**

  http://www.in.gov/indot/div/mt/itm/pubs/509_testing.pdf
- **Field Determination of Maximum Dry Density and Optimum Moisture Content of Soil**

  http://www.in.gov/indot/div/mt/itm/pubs/512_testing.pdf

ITM's and Important Links

- **Field Testing of Soil, Granular Soil, And Coarse Aggregate**
- **Link to the Office Of Geotechnical Services: http://www.in.gov/indot/2804.htm**
- **Link to the Office of Materials Management: http://intranet.indot.state.in.us/materialtests/**

Earthwork Construction

INDOT Earthwork Construction

Work Type	2011		2012		2013	
	Quantity (mcys)	Quantity (msyd)	Quantity (mcys)	Quantity (msyd)	Quantity (mcys)	Quantity (msyd)
Earthwork	30.7		24		23	
Chemical Modification		8.5		5.1		3.8

Questions?

One Point Proctor

Example:

Wt. of the mold and soil = 8.5 lbs
Wt of mold = 4.0 lbs
Wt o the soil = 4.5 lbs
Wet density of soil = 4.5 x30**(mold factor)** = 135pcf
Moisture content = 11 %
Max. wet density = 136 pcf **(Fig.1)**
Max. dry density = 122 pcf **(Fig.2)**
Optimum moisture content= 11.5% **(Fig.3)**