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Abstract:

Co-relations between Proctor Standard and Modified AASHO tests for compacting soils to their respective maximum dry densities and optimum moisture contents have been developed. Proctor Standard test data on different types of soils and the One-Point density determination at 9% moisture has been made use of for ultimate finding out the Modified AASHO maximum dry density and optimum moisture content. It has been concluded that the usual procedure of compaction test under Modified AASHO standard is laborious and time consuming which has been cut short by taking only the dry density under Proctor Standard test at 9% moisture content and thereafter compute the maximum dry density and optimum moisture content under Modified AASHO Standard.

On the basis of experimental data collected at the Irrigation Research Institute, Lahore (PAKISTAN), some mathematical relationships have been developed to compute the values of maximum dry density and optimum moisture content under Modified AASHO compaction Standard, based on the compacted density at 9% moisture, maximum dry density and optimum moisture content from Proctor Standard.

Introduction:

The single most important feature in any earth work is to ensure good compaction. Compaction substantially influences the future behaviour of any earth structure in as-much-as poor compaction leads to poor strength, high permeability, large settlements and lower erosion resistance. The dangers of slip or collapse are enhanced, and for expansive clays, the potential swell or shrink is more rapidly realised(1).

The product of earth construction whether it be a fill for a highway, an embankment for dam or canal, the support for a building or the sub-grade for a pavement, must meet certain requirements(2).

1. It must have sufficient strength to support safely its weight and that of structure or wheel load on it.
2. It must not settle or deform under load so much that it damages the soil or the structure on it
3. It must not swell or shrink excessively when specified compactive effort is applied.
4. It must retain its strength and incompressibility permanantly.
5. It must have the proper permeability or drainage characteristics for its function.

In order to obtain the required properties in the end product of earth construction the engineer must control the character of the material, the moisture and the density. Control of the moisture is ordinarily possible during the construction period. Afterwards, however, the moisture is

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largely dependent on the environment and the use to which a structure is put and often is not subject to control no matter how desirable it may be. The material in some uses, such as the up-stream face of a dam, is certain to be saturated. In other applications, such as sub-grade, the material can ordinarily be protected by drainage, but there is still danger (however remote) that it could be saturated by abnormal rainfall.

The greatest control of the soil properties is through densification. By densification it is usually possible to compensate for deficiencies in quality and for the deterioration in properties that results from increased moisture. The only property that is not improved by densification is the tendency to swell, and that must be controlled by proper selection.

From pre-historic times, builders have recognised the calue of compacting soil to produce a strong, settlement-free and water-resistant mass. Earth has been tamped by heavy logs, trampled by cattle, or compacted by rolling for more than 2000 years, but the cost of such crude work was often more than the value of compaction. On the other hand, earth that was merely dumped in place without compaction frequently failed under load and continued to settle for decades. It remained for R.R. Proctor to point out the way to low-cost effective densification.

He showed that[3]

1. There exists a definite relationship between the soil moisture content and the degree of dry density to which soil may be compacted, and
2. That for specific amount of compaction energy applied on the soil there is one moisture content termed the "optimum moisture content" at which particular soil attains its maximum density.

Such a maximum dry density-optimum moisture content relationship gives a practical and satisfactory method of construction control of earth work.

Compaction Test:

A number of arbitrary standards for determining the optimum moistures and maximum densities have been established to simulate different amounts of effort as applied by the full-sized equipment used in soil construction. The simplest and the most widely used are the "Proctor tests":

a. **Standard Proctor[4]**

(ASTM D-698, AASHO T-99, British Standard 1377: 1948):

According to these procedures a 6 lbs sample of soil to be used for a fill taken from a portion of the soil material passing the No. 8 sieve shall be air-dried, thoroughly mixed, and then compacted in a standard compaction cylinder, 4.6 inches high, 4 inches in diameter and 1/30 cu ft in volume. The compaction of the soil in the cylinder is performed in three soil layers by means of metal rammer, 2 inches in diameter, weighing 5.5 lbs. Each of the three layers of soil should receive 25 blows from the rammer falling freely from a height of 12 inches above the elevation of each finally compacted layer. The net dry weight of compacted soil should be determined, as well as the compacted moisture content. The soil is compacted at a number of different moisture contents ranging from dry to very wet and dry densities and moisture contents are determined in each case. Then the dry densities are plotted against the corresponding moisture contesnts and a smooth curve is drawn through the data points. As the moisture is increased, this curve rises to a maximum density and then declines, as shown in fig. 1. The highest point on the curve indicates the maximum density for the soil tested and is called the standard proctor density. Also, since the American Association of State Highway Officials has adopted this test procedure, it is some times referred to as the standard AASHO density. The moisture content corresponding to this maximum density is called the standard optimum moisture content.

b. **Modified Proctor (ASTM D-1557, Modified AASHO)**[5]

More recently, the U.S Corps of Engineers has felt the need for greater denstities of airport-pavements, subgrades, embankments, earth dams, etc than those indicated by the standard Proctor test, and heavier compacting machinery has been developed to meet with this need. Parallal with this development, the Corps has introduced a modification of the standard-density test in which the applied energy is greatly increased. In this modified test the soil is placed in a Proctor mould in five equal layers, and each layer is compacted by 25 blows of a tamper which weighs 10 lbs and is allowed to fall freely through a height of 18 inches. The maximum density thus indicated is called the Modified AASHO Density (or Modified Proctor Density), and the corresponding moisture content is known as the Modified optimum moisture content.

Compactive Effort:

From the foregoing discussion, it is obvious that numerical values of maximum density and optimum moisture content have significant meanings only when a particular amount of applied compaction energy is specified. The standard and modified Proctor tests are based upon two different amounts of applied energy which are 12,400 ft-lbs per cu ft and 56,200 ft-lbs per cu ft respectively. It means the effort applied in Modified AASHO test is about 4.5 times of that in Standard Proctor test.

A general relation between effort and maximum density is show in fig. 2[(2)] It is not lenear, and a large increase in effort is required to produce a small increase in density. The way in which the effort is applied has a significant effect on the density.

Experimental Data:

The valuses of maximum compacted densities and optimum moisture contents vary when the soil is compacted under Proctor and Modified AASHO standards. With the help of extensive data on Proctor and Modified AASHO standard tests on different available soils, a graph between maximum dry density (Proctor, γ_{mp}) and maximum dry density (Modified AASHO, γ_{ma}) was plotted on a natural scale. The trend of the plot suggests a parabola of second degree (fig. 3) of which the equation has been evolved as:

$$\gamma_{ma} = 0.02(\gamma_{mp})2 - 3.79\ \gamma_{mp} + 293.4 \ldots\ldots\ldots\ldots (1)$$

in which

γ_{ma} = maximum dry compacted density under modified AASHO Standard (lbs/cu ft)

γ_{mp} = maximum dry compacted density under Proctor standard (lbs6cu ft) and 0.02, 2.79 & 293.4 are constants

The second parameter of compaction test viz. optimum moisture contents were related by plotting optimum moisture content (Proctor, mo_p) and optimum moisutre content (Modified AASHO, mo_a) on natural scale. The trend of the plot again suggests a parabola of second degree (fig. 4) of which the equation has been evolved as:

$$mo_a = -0.036\ (mo_p)^2 + 1.754\ mo_p - 5.564 \ldots\ldots\ldots\ldots (2)$$

in which

mo_a = optimum moisture content under Modified AASHO standard (%)

mo_p = optimum moisture content under Proctor standard (%) and 0.036, 1.754 & 5.564 are constants.

Uptil now we have achieved the relationship between the compaction test results obtained by the application of the above two standards. Let us consider now the determination of Modified AASHO compaction test data based on Proctor standard One-Point method[6]. Briefing the One-Point method, we know that:

$$481.6 - \gamma_9 = r \cos \Theta \quad \ldots \ldots (3)$$

$$\gamma_{mp} + 359.2 = r \sin \Theta \quad \ldots \ldots (4)$$

in which

γ_9 = dry compacted density at 9% moisture (Proctor standard, lbs/cu ft)

γ_{mp} = maximum dry density (Proctor standard, lbs/cu ft)

r = 602.45 lbs/cu ft

Θ = angle of inclination of the radius with Y_9 –axis (degrees)

and

$$mo_p = 376 \exp(-0.0287\, \gamma_{mp}) \quad \ldots \ldots (5)$$

The application of the equations from 1 to 5 will be as under:

step 1.
determine dry compacted demisity (γ_9) at 9% moisture by Proctor standard method

step 2.
substitute the value of γ_9 in eq. (3) to determine Θ

step 3.
substitute the value of Θ in eq. (4), to determine maximum dry compacted density (γ_{mp})

step 4.
the value of γ_{mp} thus computed in step 3 be put in eq. (1) to determine the maximum dry compacted density under Modified AASHO standard (γ_{ma})

step 5.
for obtaining the value of optimum moisture content (mo_p), substitute γ_{mp} in eq. (5)

step 6.
substitute the value of mo_p in eq. (2) and find out the value of mo_a.

In this way we have computed both the parameters of Modified AASHO compaction test by involving a single observation, determined from Proctor standard compaction method.

Solved Example:

A semi plastic soil when compacted at 9% moisture by Proctor standard compaction method gave a dry density of 110 lbs/cu ft. Compute the Modified AASHO maximum dry density and optimum moisture content?

Here

$\gamma_9 = 110$ lbs/cu ft

substituting this value in eq. (3) we get:

$481.6 - 110 = 602.45 \cos \Theta$

$\Theta = 51.92$ degrees.

Which on further substitution in eq. (4) yields the value of $\gamma_{mp} = 115.0$ lbs/cu ft.

The value of γmp is again put in eq. (1):

$\gamma_{ma} = 0.02 \times (115)^2 - 3.79 \times 115 + 293.4$

$= 122.1$ lbs/cu ft.

For computing the optimum moisture content (mo_a), substitute first the value of $\gamma_{mp} = 115$ lbs/cu ft in eq. (5) to get:

$mo_p = 376 \exp(-0.0287 \times 115)$

$= 13.86\%$

which on further substitution in eq. (2) yields the value of mo_a:

$mo_a = -0.036 \times (13.86)^2 + 1.754 \times 13.86 - 5.564$

$= 11.83\%$

The same soil sample was subjected to actual Modified AASHO compaction test. The values of maximum dry desnity and optimum moisture content were found to be 123.1 lbs/cu ft and 12.0% respectively. The variations between the actual and computed values are thus + 0.81% and + 1.44% which are surely negligible from practical point of view.

Conclusion:

Achieving dry density of soil at 9% moisture by usual procedure of Proctor standard compaction test, it is possible to determine both maximum dry density and optimum moisture content of Modified AASHO standard with the help of mathematical relationships developed in this paper. Table 1 gives some of the values of γ_{ma} and mo_a determined experimently and computed from the formulaes based on γ_9. The per cent variations of determined and computed values of γ_{ma} and mo_a are $\pm$ 1.55 and $\pm$ 3.29 respectively which are assumed to be within a reasonable range for all practical purposes. Table 2 has been prepared including Proctor compacted maximum dry density (γ_{mp}), Modified AASHO compacted maximum dry density (γ_{ma}), their differences, relative compactness and the per cent variation of densities w.r.t. γ_{mp}. From this table it has been concluded that the relative compactness (γ_{mp}/γ_{ma}) x 100 ranges from 81.1 to 94.5 per cent resulting in per cent variations ($\frac{\gamma_{ma} - \gamma_{mp}}{\gamma_{mp}}$) x 100 from 23.4 to 6 per cent when the soil ranges from clayey to sandy texture. It is really interesting to mention over here that these variations, when Proctor maximum dry density ranges between 110 – 126 lbs/cu ft, are 7.5 to 6 per cent which means that only 1.5 per cent gain in density can be achieved between the above range or in other words the effect of increased compactive effort for this range is almost uniform.

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Table: 1.1

COMPACTION STATEMENT OF TEST DATA OBTAINED FROM PROCTOR STANDARD AND MODIFIED AASHO COMPACTION TEST

Lab. sample	Proctor Compaction test			Modified AASHO compaction test		Modified AASHO compaction test from formula		%variations	
	dry density (γ_9) lbs/cft	optimum moisture content %	maximum dry density lbs/cft	optimum moisture content %	maximum dry density lbs/cft	optimum moisture content %	maximum dry density lbs/cft	optimum moisture content	maximum dry density
1.	82.4	26.7	92.4	15.2	113.5	15.6	114.0	+2.63	+0.44
2.	83.8	26.0	93.2	15.5	114.2	15.7	113.9	+1.29	–0.27
3.	86.7	24.0	95.8	15.9	114.4	15.8	113.9	–0.63	–0.44
4.	88.5	23.0	97.3	15.8	113.7	15.7	114.0	–0.63	+0.26
5.	90.4	21.8	99.0	15.6	114.0	15.6	114.2	±0	+0.18
6.	92.4	20.9	100.7	15.3	114.6	15.4	114.6	+0.65	±0
7.	94.5	19.9	102.4	15.0	115.8	15.1	115.0	+0.67	–0.69
8.	97.3	17.5	104.8	13.2	117.0	13.2	115.9	±0	–0.95
9.	98.6	18.1	105.8	14.2	116.8	14.4	116.3	+1.41	–0.43
10.	100.5	15.5	107.4	13.2	117.2	13.0	117.0	–1.71	–0.17
11.	101.6	14.8	108.3	12.6	117.8	12.5	117.5	–0.72	–0.25
12.	102.8	14.6	109.3	12.6	118.0	12.4	118.1	+1.59	+0.08

Table 1.2

COMPACTION STATEMENT OF TEST DATA OBTAINED FROM PROCTOR STANDARD AND MODIFIED AASHO COMPACTION TEST

Lab. sample	Proctor Compaction test			Modified AASHO compaction test		Modified AASHO compaction test from formula		%variations	
	dry density (γ_9) lbs/cft	optimum moisture content %	maximum dry density lbs/cft	optimum moisture content %	maximum dry density lbs/cft	optimum moisture content %	maximum dry density lbs/cft	optimum moisture content	maximum dry density
13.	104.2	14.4	110.4	12.2	118.0	12.2	118.7	±0	+0.63
14.	105.2	13.2	111.2	11.3	118.7	11.3	119.3	±0	+0.47
15.	107.2	13.0	112.8	11.4	119.5	11.2	120.4	–1.75	+0.72
16.	107.7	12.8	113.2	11.0	119.4	11.0	120.7	± 0	+1.05
17.	108.4	12.7	113.7	11.1	120.3	10.9	120.0	–1.80	–0.25
18.	109.5	13.6	114.6	11.8	122.4	11.6	121.7	–1.43	–0.55
19.	111.5	12.2	116.2	10.5	123.6	10.5	123.1	±0	–0.44
20.	113.4	12.0	117.6	10.3	122.4	10.3	124.3	±0	+1.55
21.	114.4	11.3	118.4	9.6	126.0	9.7	125.0	+0.62	–0.79
22.	115.4	11.0	119.2	9.4	124.4	9.4	125.8	±0	+1.13
23.	116.9	10.7	120.3	9.2	127.7	9.1	126.9	–1.28	–0.62
24.	120.5	11.0	123.0	9.1	129.8	9.4	129.8	+3.29	±0
25.	124.5	10.1	126.0	8.6	133.9	8.5	133.4	–1.16	–0.37

Table: 2

COMPUTATIONS FOR VARIATIONS BETWEEN PROCTOR STANDARD MAXIMUM DRY DENSITY (γ_{mp}) AND MODIFIED AASHO STANDARD MAXIMUM DRY DENSITY (γ_{ma}) OF DIFFERENT TYPES OF SOILS

Lab. sample No.	Max. dry density lbs/cu ft Proctor (γ_{mp})	Max. dry density lbs/cu ft Modified AASHO (γ_{ma})	Difference ($\gamma_{ma} - \gamma_{mp}$) lbs/cu ft	Per cent compaction (γ_{mp}/γ_{ma}) x 100	Per cent variations $\left[\frac{\gamma_{ma} - \gamma_{mp}}{\gamma_{mp}}\right] \times 100$
1.	92.4	114.0	21.6	81.1	23.4
2.	93.2	113.9	20.7	81.8	22.2
3.	95.8	113.9	18.1	84.1	18.9
4.	97.3	114.0	16.7	85.4	17.2
5.	99.0	114.2	15.2	86.7	15.4
6.	100.7	114.6	13.9	87.9	13.8
7.	102.4	115.0	12.6	89.0	12.3
8.	104.8	115.9	11.1	90.4	10.6
9.	105.8	116.3	10.5	91.0	9.9
10.	107.4	117.0	9.6	91.8	8.9
11.	108.3	117.5	9.2	92.2	8.5
12.	109.3	118.1	8.8	92.5	8.1
13.	110.4	118.7	8.3	93.0	7.5
14.	111.2	119.3	8.1	93.2	7.3
15.	112.8	120.4	7.6	93.7	6.7
16.	113.2	120.7	7.5	93.8	6.6
17.	113.7	120.0	6.3	94.7	5.5
18.	114.6	121.7	7.1	94.2	6.2
19.	116.2	123.1	6.9	94.4	5.9
20.	117.6	124.3	6.7	94.6	5.7
21.	118.4	125.0	6.6	94.7	5.6
22.	119.2	125.8	6.6	94.8	5.5
23.	120.3	126.9	6.6	94.8	5.5
24.	123.0	129.8	6.8	94.8	5.5
25.	126.0	133.4	7.4	94.5	5.9

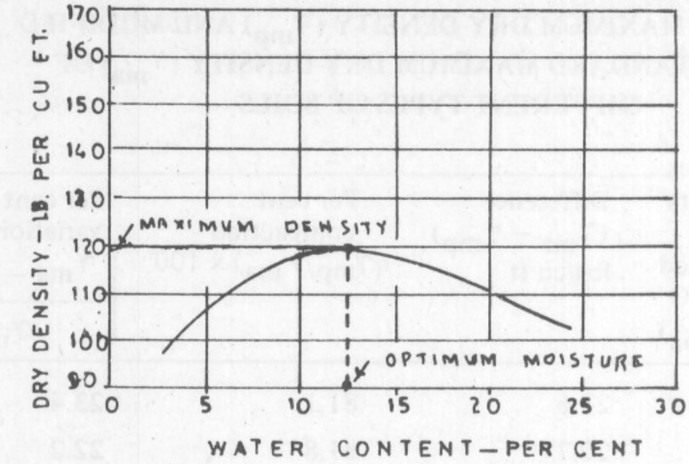
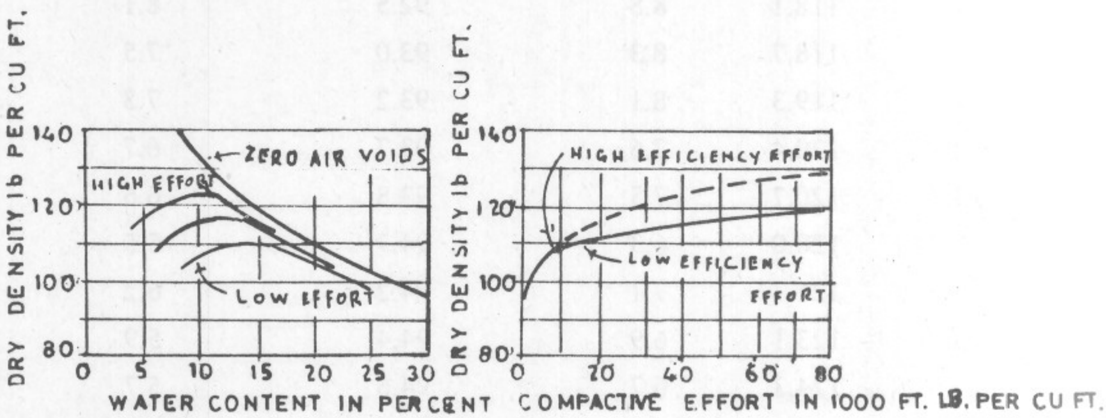


Fig. 1 – MOISTURE – DENSITY CURVE OF A COHESIVE SOIL FOR ONE METHOD OF COMPACTION AND MAXIMUM MOISTURE FOR A SPECIFIED DEGREE OF COMPACTION.



a – MOISTURE DENSITY CURVES FOR DIFFERENT POMPACTIVE EFFORTS

b – MAXIMUM DENSITY AS A FUNCTION OF COMPACTIVE EFFORT

Fig. 2 EFFECT OF COMPACTIVE EFFORT ON MOISTURE DENSITY CURVES AND MAXIMUM DENSITY

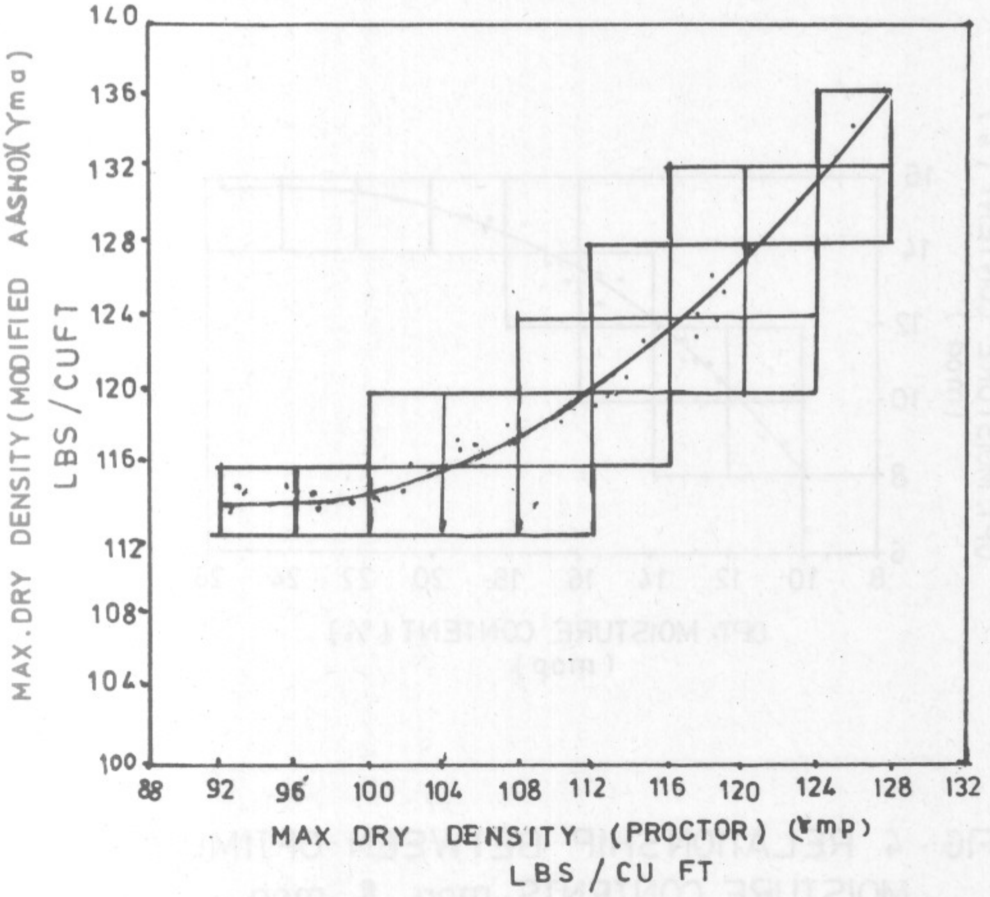


Fig 3. Relation-ship between Maximum Dry density (Proctor) and maximum Dry density (Modified AASHO)

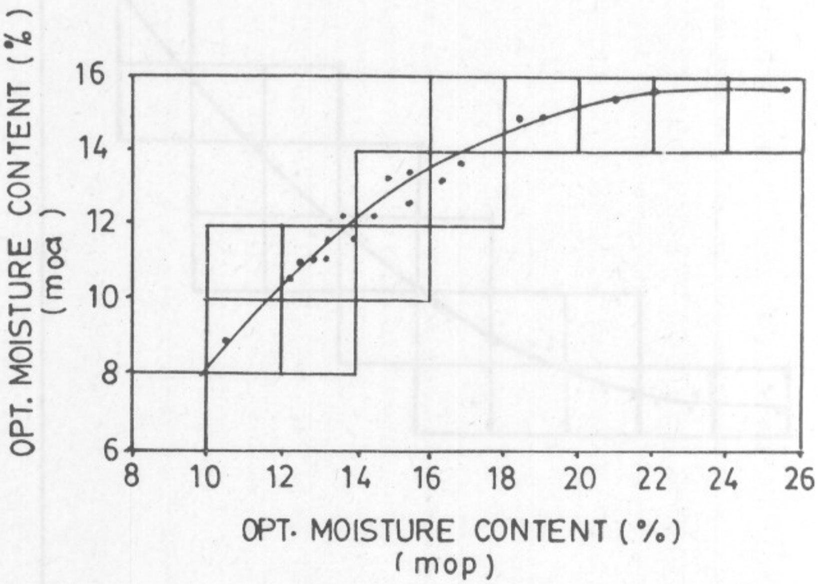


FIG:- 4 RELATIONSHIP BETWEEN OPTIMUM MOISTURE CONTENTS moa & mop