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GENERALIZATION OF LYSE RULE

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1 Introduction

It is well known that slump test is the only easily available and used to assess the workability of concrete mix in site and laboratory. The present investigation emphasizes on the determination of workability characteristics of concrete with aggregates of different sizes and shapes. Hence slump test has been used in the present investigation to assess the workability characteristics and hence to generalize the workability behavior so as to provide a rational means to achieve designed mix. The approach will enable a simple and convenient method to obtain the targeted mix instead of many trails adopted in the conventional methods.

According to Lyse's rule it is not possible to predict the slump as water content changes. The need for this assessment arises when appropriate corrections have to be applied to the water content to obtain the same slump without effecting any change to Water /cement ratio. Further the classification of workability is over a range, which is too wide for identifying as a specific type, viz., very low, low medium and high. Hence the possibility of generalization of Lyse rule has been examined in this section.

For analysis of the above states, cement based composites are considered to be made up of two phases, viz., cement mortar matrix and coarse aggregate. The synergy between different constituents at various stages of formation and transformation are examined in this investigation. The underlying basic framework is Lyse rule (1932) which states that

For given materials the CONSISTENCY OF FRESH CEMENT CONCRETE is determined exclusively by the free water content of the mix. This is LYSE'S rule (1932) , i.e., constant water content for constant concrete consistency. Thus for a given material, a particular consistency of the fresh concrete is independent of the water -cement ratio of the mix.

1.2 Generalization of Slump Values. (PCA Curves- 6 charts)

As in the case of clays, where liquid limit water content form the reference state for analysis of soil behavior, similar parameter cannot be identified for fresh concrete. As such it has to be arbitrarily identified. It cannot be water content since slump values are to be considered and analyzed. Let us consider the slump versus water content plots shown in figures 1.1 to 1.6 (Portland Cement Association Proceedings 2004**)** . It can be seen that as the maximum size of aggregate in the mix is higher for the same water content the slump is higher

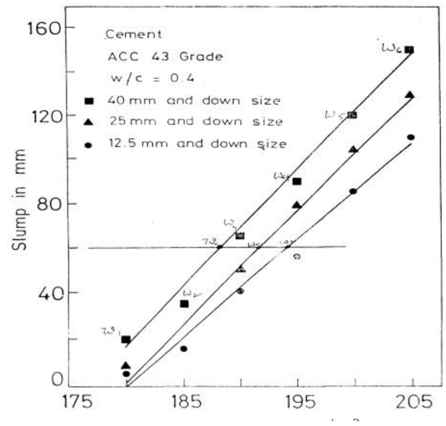

Fig- 1.1PCA CHART-1 (Portland cement Association Proceedings-2004)

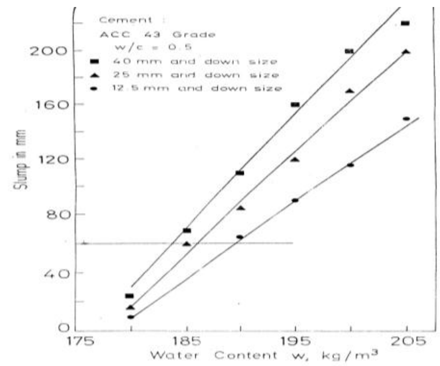

Fig1.2 PCA CHART-2 (Portland cement Association Proceedings- 2004

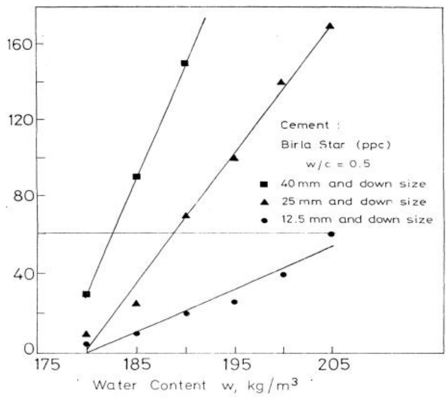

Fig – 1.3 PCA CHART-3 (Portland cement Association Proceedings- 2004

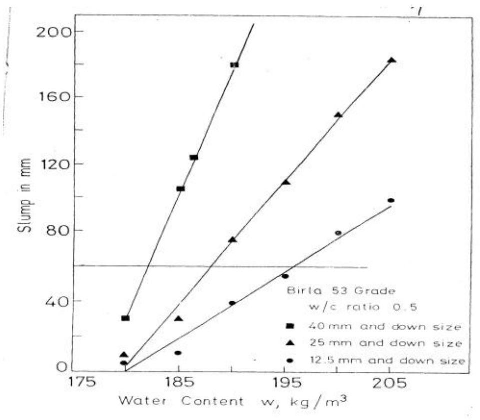

Fig 1.4 PCA CHART-4 (Portland Cement Association Proceedings- 2004

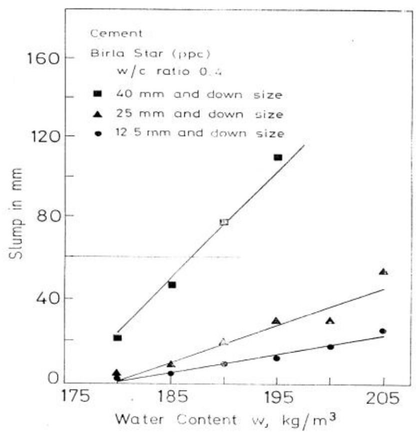

Fig – 1.5 PCA CHART-5 (Portland cement Association Proceedings- 2004

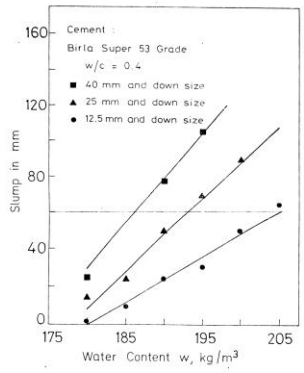

Fig- 1.6 PCA CHART-6 (Portland Cement Association Proceedings- 2004)

The above PCA 6 charts are analyzed for generalization of workability characteristics by normalizing the values by identifying a normalization parameter and the following table is prepared. The procedure followed in preparing the following table 1.

- Fig NO : Fig- 1.1 PCA CHART-1 (Portland cement Association Proceedings- 2004)
- Type of Cement : ACC 43 Grade
- Water Cement ratio : 0.40
- Size of Angular aggregate : 40mm and down size
- Water Content at the slump value of 60mm – $W_{@60}$ = 188 lits /m³
- For all the 6 points (1.2…..6) shown on the chart, Corrrespoinding water Contents are found (w)
- The values of Normalized state parameter w/w@60 are calculated
- Similar procedure is followed for the remaining 2 graphs ie 25mm downsize and 12.5mm down size coarse aggregate and presented in **table 1**

Table- 1 Normalization of Slump values from PCA chart 1- for w/c ratio 0.40 and ACC-43 grade cement

Type of Cement	ACC-43 Grade				Chart-1	
w/c ratio →	0.40					
Size of Angular Aggregate →	40mm down size		25mm downsize		12.5mmdownsize	
Wc @ slump value of 60mm, → w @s=60mm- kg/m³	188		192		194	
Points on the Chart ↓	wc (w)	w/w @s=60	wc (w)	w/w @s=60	wc (w)	w/w @s=60
1	181	0.962	180	0.937	180	0.958
2	186	0.989	190	0.989	185	0.953
3	189	1.005	196	1.020	190	0.979
4	195	1.037	201	1.046	195	1.005
5	200	1.063	206	1.072	200	1.030
6	205	1.090	-	-	206	1.061

Similarly 6 tables were prepared from the charts 1- 6. the Fig 1 is drawn using MS Excel- Chart Wizard-
Ie Normalized State Parameter versus Slump relation is drawn. All the normalized values are lie in a band of straight line.. The equation of trend line is

$$\frac{W@S{=}60}{W} = 1.05-0.0008S \quad \text{..........1}$$

Where $w_{@60}$= Water content at the slump value of 60mm
w= water content in lits per m^3
and s= slump in mm

S= Slump-mm
r = Coefficient of Correlation
N= No of Points

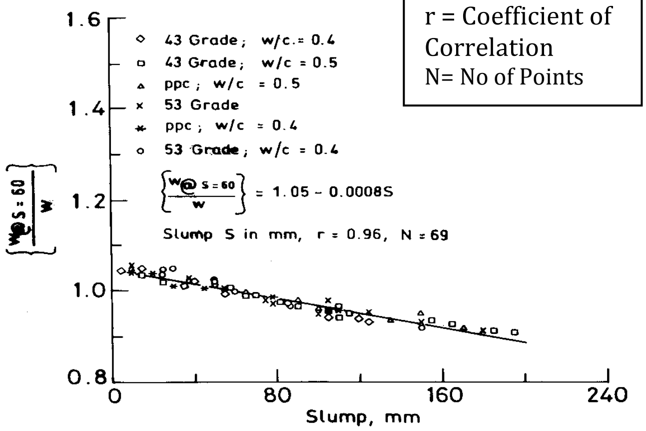

Fig 1.- Normalized State Parameter versus Slump relation for the 40mm ,25mm and 12.5mm downsize angular aggregate

From the typical slump versus water content plots (fig no- 1 to fig no- 1.6 Slump data published in PCA Manual 2004) ,it can be seen that as the maximum size of aggregate in the mix is higher for the same water content the slump is higher . This is in order since surface area to be coated to prevent direct interference between coarse aggregate decreases and same consistency of cement mortar matrix would impart higher slump to the concrete. It can also be seen that the slump values are also affected by the grade of cement and the water cement ratio. As the grade is higher and the water cement ratio is higher , the slump obtained is also higher. This can be attributed to deformation and flow of mortar matrix . Now it is necessary to identify normalization parameter to develop a phenomenological parameter to develop a phenomenological model for analysis and assessment

The liquid limit water content of clays is a state parameter, which reflects the physco –chemical interactions between clay and water. It is a state parameter exhibiting same order of shearing resistance of clay- water systems and hence forms normalization parameter. Similar parameter to reflect cement water interactions is not identified . Water content of a particular slump $w_{@s}$,could be a parameter for this purpose of normalization. Considering the inverse of w/ $w_{@s}$ versus slump, a phenomenological relationship should be possible similar to w/w_L versus shearing resistance relationship

Wide range of slump data with variations in the grade of cement (43 and 53 grade cement) , water cement ratio of 0.4 and 0.5 and size of coarse aggregates 40,25,12.5mm and down sizes ,have been considered in obtaining the generalized relation. Considering water content for 60 mm slump as arbitrary reference state, it has been possible to obtain functional relation of the form (fig 1), it can be seen that the relation of the form

$$\frac{W@S{=}60}{W} = 1.05 + 0.0008S$$

with a higher correlation coefficient of r=0.960 is possible. This can be regarded as Generalized Lyse's Rule for Slump. This relation permits to calculates the water content required to the obtain the slump required with the minimum input data. The data required are specific grade of cement, fine and coarse aggregate and water-cement ratio This reinforces that development of phenomenological model is possible in terms of normalized state parameter as slump values vary. For engineering usage, this form of relationship is not convenient. It is always the case that for a required value of workability as measured in the slump test the water content required is to be assessed. Hence reference parameter need be in terms of slump at particular value of water content.

In this study, a terminology water contents used, which is not common in the field of concrete. Water content is defined as the ratio volume of water in ltr. to the volume of concrete in cubic meter.

$$\text{Water content (w)} = \frac{\text{Volume of water in Ltr}}{\text{Total volume of concrete}}$$

3.0 List of Materials Used in the Present Slump Test Experimental Program

The materials used in present slump test study are as follows:

- Cement
- sand
- Water
- Aggregates

The details are specified in Table 2

Cement

Physical properties of cement used in the present study are given in the table 3. Commercially available cement is used.

Sand

Sand used in this study is river sand (Tunga Bhadra River) . The physical properties are given in the table 4

Water

Tap water has been used in the present experimental program.

Aggregates

In the present study, crushed (angular) and rounded aggregates of different sizes are used and their physical properties is given in Table 5. 40mm down size aggregates, 20mm down size aggregates and 10 mm down size aggregates were respectively passing through 40 mm, 20 mm and 10 mm sieves and were retained on 20 mm, 10 mm and 4.75 sieves.

Table 6 presents Volume Of Dry Rodded Coarse Aggregate Per Unit Volume Of Concrete (Nagraj and etal-1999)

Table 2. List of The materials used In the present experimental program

Cement	43 Grade	
Sand	River Sand	
Type / Size of Aggregate	Rounded	≤ 10.0 mm
		≤ 20.0 mm
		≤ 40.0 mm
	Angular	≤ 10.0 mm
		≤ 20.0 mm
		≤ 40.0 mm

Table 3 Physical properties of cement used In the present experimental program

CEMENT	43 GRADE CEMENT
Normal Consistency	28%
Initial Setting Time	90 min.
Final Setting Time	190 min.
Specific Gravity	3.15

Table 4 Material properties of fine aggregate

Specific Gravity	2.55
Finenesss Modules	3
Zone	I BIS (383-1970)

Table 5 . Material properties of coarse aggregate

	Angular aggragate			Pebbels		
	40mm ds	20mm ds	10mm ds	40mm ds	20mm ds	10mm ds
Rodded Density-Kg/m³	1424	1428	1375	1695	1684	1551
Volume of dry rodded density of coarse aggregate per unit volume of concrete (1m³)	0.70	0.60	0.44	0.70	0.60	0.44
Specific Gravity	2.562	2.562	2.562	2.615	2.615	2.615

Table 6- Coefficients for the given values of fineness modules of sand and maximum size of aggregate for the calculation of volume of Dry rodded coarse aggregate per unit volume of Concrete (NAGARAJ T.S.and ZAHIDA BANU 1999)

Table 6

Maximum Size of Aggregate (mm)	Fineness Modules of Sand			
	2.40	**2.60**	**2.80**	**3.00**
	Coefficients-k			
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53

20	0.65	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.76	0.74	0.72	0.70
50	0.78	0.76	0.74	0.72
70	0.81	0.79	0.77	0.75
150	0.87	0.85	0.83	0.81

3.1 Comprehensive method of mix proportion

In the present investigation a COMPREHENSIVE APPROACH OF MIX DESIGN (NAGARAJ T.S.and ZAHIDA BANU 1999) has been used to prepare the desired mix. This approach is based on the specific advantage of the British and ACI methods of proportioning concrete mixes synthesis with generalized Abrams law for strength and Lyse's Rule for workability. The following are the steps of the procedure involved in mix design by ***Comprehensive approach.***

In order to obtain desired mix for different water contents (w) and water cement ratios following modified steps are used.

Step 1 *Fix the water cement ratio (say).*

Step 2 *Fix the Water content (say).*

Step 3 *Based on the maximum size of the aggregate, its bulk density and fineness modules of sand arrive at the coarse aggregate content per unit volume of concrete from the table 6 (Nagraj and Zaheda Banu 1999).*

Step 4 *Based on the water cement ratio arrive at the cement content and finally using the absolute volume method and specific gravity of fine aggregates arrive at the fine aggregate content.*

Illustrative Example for Mix Design

Materials

Coarse Aggregate
:40 mm Angular

Bulk Density
:1424.00 Kg/m³

Specific Gravity :2.56

Fine Aggregate

Fineness Modules
:3,00

Specific Gravity (SSD) :2.55

(SSD: Surface saturated Density)

Density of sand : 2525 kg/m³

Grading of Aggregates :Zone I of BIS (383-1970)

Ordinary Protland cement

Specific Gravity of cement :3.14

Normal Consistency
:28

Compressive strength :43 MPa

Chosen Water cement Ratio (w/c) :0.4

Chosen Water content :140lt/m³

Step 1: *Determination of Total weight of cement for M^3*

W/C=0.4

C=W/o.4

C=140/0.4 =350 kg.

Step2: *Determination of total weight of coarse aggregate per cubic meter from the table (6) coarse aggregate per unit volume is 0.70*

Total weight of coarse aggregate = k x bulk density

Where k=coefficient 0.70 (from table 5.11 for the maximum size of aggregate 40mmand fineness modules of sand is 3.00)

he =0.70 x 1424
=997.00 kg.

Step 3: *Determination of total weight of fine aggregate per cubic meter by absolute volume method is calculated as follows*

Step 4 *: Similar Procedure is followed for the remaining trails*

Table-7

1 Type of aggregae			*40mm ds Angular*	
w.c.			*0.40*	
		Mass-kg		*Volume-m³*
Water	*140 Lits*	*140*		*0.140*
Cement	*-*	*350*	*350/3140*	*0.111*
CA	*0.7x1424*	*997*	*997/2562*	*0.389*
				0.640
FA (Sand)	*0.36x2525*	*909*		*1-0.640=0.360*
Total		***2396 kg/m³***		

3.2 Apparatus used in the present slump test experimental work

Equipment used in the present experimental program consist of

1.Slump cone (as specified in BIS)

2.Measuring Jar

3.Trowel

4.Steel Tamping Rod

3.3.3 Procedure of experimental program

For the determination of workability characteristics of concrete mix using slump cone test following steps were adopted.

Step 1. *Slump Mould is placed on a smooth flat and non absorbent surface.*

Step 2. *A thin layer of oil is applied on the inside of the mould and on flat surface to eliminate friction.*

Step 3. *The dry ingredient of the concrete are thoroughly mixed till a uniform colour is obtained and then the specified quantity of water is added.*

Step 4. *The mixed concrete now placed in mould in about 3 layers with each layer approximately measuring one third of the total volume.*

Step 5. *The concrete is compacted by applying 25 strokes with the help of a tamping rod uniformly all over the area in each layer.*

Step 6*. The level of concrete is maintained at the surface.*

Step 7*. The mould is immediately and gently removed, ensuring its movement in vertical direction.*

Step 8*. When the concrete experience settlement completely, vertical substance of the concrete in millimeter which is the required slump of concrete is measured.*

4.0 Workability characteristics of concrete with angular aggregate an rounded aggregates are drawn as shown in fig 2-5 for water cement ratios 0.40 and 0.50

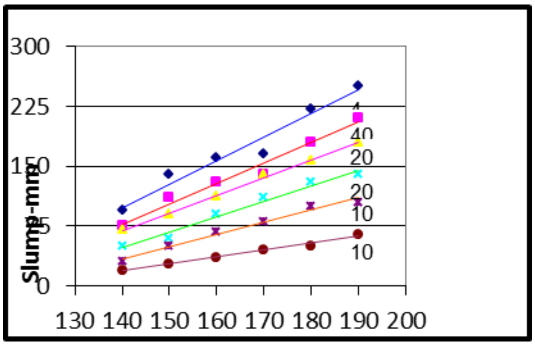

Fig- 2 Workability Characteristics of Concrete with angular and rounded aggregates (All Size) wc=0.40

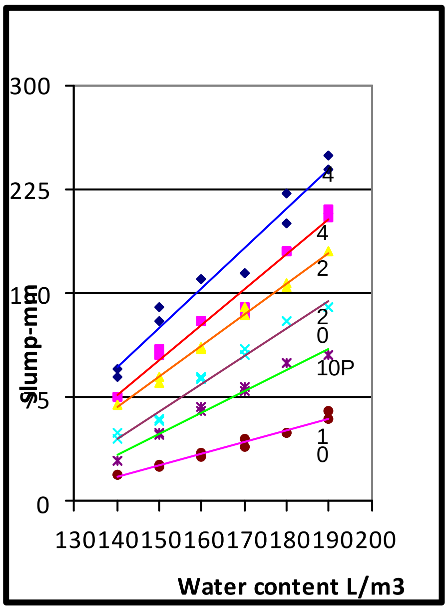

Fig-3 Workability Characteristics of Concrete with angular and rounded aggregates (All Size) wc-0.50

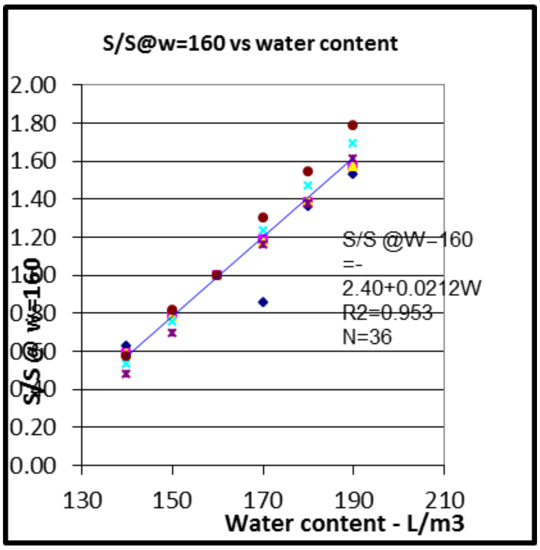

Fig-4 Generalization of Workability characteristics of concrete for both angular and rounded aggregates for w/c ratio 0.40

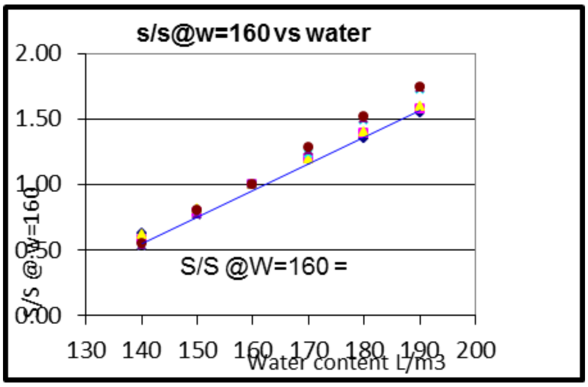

Fig- 5 Generalization of Workability characteristics of concrete for both angular and rounded aggregates with w/c ratio 0.50

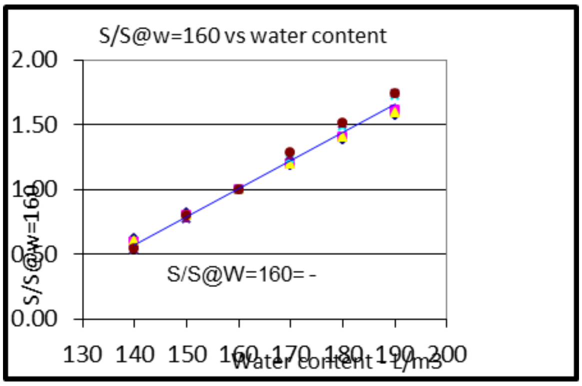

Fig- 6 Generalization of Workability characteristics of concrete for both angular and rounded aggregates for w/c ratio 0.40 and 0.50

6 Generalization of Workability Relationship for various combinations

From equations obtaine in graphs (fig-4,5,6) the constants (A and B) , Coefficient of correlation (R) and number of points (N) are tabulated in the table 8 for water cement ratio of 0.40,0.50 and combined 0.40, 0.50 **Summary of constants A,B , R and Number of trails\ (N), for w/c ratio0.40 and 0.50 is presented in table 8**

The equations obtained are

$$\frac{S}{S@160} = -2.40 + 0.0212\ w$$

$$\frac{S}{S@160} = -2.34 + 0.0206\ w \quad \text{and}$$

$$\frac{S}{S@160} = -2.48 + 0.0218\ w$$

Table-8

Combination- All size – 40P, 40A, 20P, 20A, 10P, 10A					Aggregate Size-mm	w.c
	A	B	R	N		
1	-2.40	0.0212	0.953	36	All	0.40
2	-2.34	0.0206	0.99	36	All	o.50
3	-2.48	0.0218	0.986	36	All	0.40, 0.50

S_n = A+B(w)

1) w.c=0.40 , All Size

$$\frac{S}{S@160} = -2.40 + 0.0212(w)$$

R=0.953
N=36

2) wc=0.50 , All Size

$$\frac{S}{S@160} = -2.34 + 0.0206\ (w)$$

R=0.99
N=36

3) wc= Combined 0.40 and 0.50, All Size

$$\frac{S}{S@160} = -2.48 + 0.0218(w)$$

R=0.986
N=36

Prediction of workability characteristics of various sizes of aggregates are presented in Table 9

Prediction of workability characteristics of various sizes of aggregates are presented in Table 5.30

Table- 9 **Prediction of workability characteristics of various sizes of aggregates**
Table-9

Sl NO	Size/ Shape of Aggt-mm	wc	Slump-mm	W_{act}	W_{Pre}	Deviation Factor $= W_{Pre}/W_{act}$
1	40P	0.40	166	160	159	0.99
2	40A	0.50	130	160	157	0.98
3	20P	0.40	110	160	160	1.00
4	20A	0.40	58	160	169	1.05
5	10P	0.50	50	160	158	0.99
6	10A	0.50	27	160	160	1.00
7	40P	0.40,0.50	135	160	156	0.98

Specimen Calculation:

For 40P, for WC=0.40

$$\frac{S}{S@160} = -2.40 + 0.0212w$$

From the Table – 5.25

for w= 150 lits S_{act} = 130mm

$130/S_{@160}$ =-2.40 + 0.0212 (150)

130/ S @160 = 0.78

$S_{@160}$ = 130/0.78= 166mm

160/ 166= -2.40 + 0.0212w

w= 158.63 Liters

The Deviation factors are all calculated in the same manner and presented in table- 9

7.0 Results and Discussions:

Obviously, from the figures (fig 5.8 to fig 5.19) the workability of fresh concrete depends up on practical situation encountered and the equipment deployed for placement and compaction. For given water content and water cement ratio, the workability depends up on the shape, size and gradation of fine and coarse aggregates. Rounded aggregates need less water than the angular/ crushed aggregates. Finer the aggregates, lesser is the workability as the specific surface increases. In this context, the fines content sand (below 600microns) will contribute to many of specific flow characteristics of concrete because of its high specific surface. The latest recommendations of the British method are probably based on this fact.

In all the mix proportioning methods like BIS, ACI and British method water content is prescribed for particular maximum size of aggregate and for particular range of workability of concrete mix

Aggregates constitute the bulk of total volume of concrete, with cement paste being required to form cohesive membrane around the fine aggregate particles and in turn around the coarse aggregates. In this state direct frictional interaction between aggregate particles is prevented there by imparting required workability to the mix for placement, with the potential for the paste to develop the microstructure for intended strength development with age. It is needed to have good distribution and grading of various sizes of coarse aggregates, so that the cement mortar required in excess of the voids due to coarse aggregates would be minimum resulting into a highly compact mass.

From table 9 , it can observed that ,Generalization of workability characteristics of concrete with different sizes and shapes of the aggregates is possible. Hence it is possible to reduce the number of trails to one during mix design.

8.0 Concluding Remarks

Following conclusions were drawn from the present experimental investigation.

1. In medium to low slump range, the relationship between workability and water content was linear. Test results with high slump range were not considered for the analysis in the study.
2. Angular aggregates show sufficient resistance to workability compared to rounded aggregates.
3. As the size of the aggregates increases, workability characteristics of concrete increases because of decrease in surface area of the aggregates.
4. Generalization of workability characteristics of concrete with different sizes and shapes of the aggregates is possible. Hence it is possible to reduce the number of trails to one during mix design.
5. Comprehensive approach is a good method to carry out mix design as it utilizes advantages of both BS and ACI method of mix proportioning.

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