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Original Research Article

Operational Relation of Cement to Estimate Strength

Anjay Kumar Mishra[1*], Khem Raj Joshi[2], Damyanti G Badagha[3]

[1]Post Doctorate Scholar, Srinivas University, India & Visiting Faculty, United Technical College, Chitwan, Nepal
[2]Registrar, Nepal Engineering Council, Kathmandu, Nepal
[3]Associate Professor, Civil Engineering Department, S N Patel Institute of Technology & Research Centre, Umrakh, Gujarat, India

***Corresponding Author**
Anjay Kumar Mishra

Email: anjaymishra2000@gmail.com
Orcid ID: 0000-0003-2803-4918

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Abstract: Nepal Bureau of Standard and Metrology (NBSM) have published Nepal Standard (NS) for physical and chemical requirements of different grade of OPC. Likewise, India, Japan, United States and other countries have published their own standard for physical and chemical properties of OPC. To confirm grade of cement, it takes 28 days. So, estimation of 28 days strength based on 3 days and 7 days compressive strength might help to save time. Before 2076, NBSM has published NS only for 33 grade of OPC, so cement industries in Nepal used to follow Indian standard (IS) standard (IS) for grade 43 & grade 53 due to absence of code related to these grades. As a result, the linear relationship between 3 days, 7 days and 28 days compressive strength model was determined with adjusted square of regression (R^2) value of 0.783. It is recommended that determined relationship between compressive strength of OPC at different age can be used to estimate 28 days compressive strength of cement from the strength obtained at 3 days and 7 days test.

Keywords: Compressive strength, OPC cements, comparison, relation, Standards.

INTRODUCTION

Concrete is required and compressive strength of concrete also depends on grade of cement. Grade of cement is 28 days compressive strength of cement. Due to factors such as age of cement, stacking techniques, adulteration, compressive strength of cement must be confirmed before starting mix design of concrete. During mix design grade of cement can determine various factors such as minimum water cement ratio and minimum cement content. To find out grade of cement it takes 28 days and to confirm mix design of concrete it takes another 28 days. Hence long duration of time is required just to confirm mix design of concrete. In the case where time is constraint, estimation of 28 days compressive strength based on 3 days and 7 days compressive strength can be useful.

Nepal standards have not classified ordinary Portland cement based on grade, it provides physical and chemical parameter only for 33 grade cement before 2076. But Nepal has many cement factories which claims to manufacture 43 grade and 53 grade cement using parameter set by Indian standards [1]. Maximum magnesia content for all three grade of cement is 6% [2], Nepal standards suggests maximum magnesia content for 43 & 53 grade is 5% [3]. Controversies arise and many cement factories which have been run successfully from past have failed in quality standard and were banned by NBSM. Later NBSM have to release its ban over these cement industries. In context of Nepal, cement usually failed to achieve quality requirement for compressive strength and magnesia content. Compressive strength test was common but chemical tests were done in only larger projects, so it became necessary to study about issue of magnesia content in detail.

Nepali cement industries formerly followed Indian standard as quality parameter and now NS572: 2076 came in 2076, which have different parameter differ with Indian standard. It becomes difficult for Nepal cement industries to suddenly change their quality standards. Due to which cement industries were failing in their quality requirements. So, it become necessary to compare Indian and Nepali standard.

Different construction related departments have their own general specification, which they follow in most of their construction project. No separate specification was prepared for each construction projects. Contractors have to follow that specification during quality control of cement and implementation of works. Contractors usually choose cement based on advertisement or low-priced cement or from those suppliers who provide cement in debt. But it must be chosen based on its property and requirement of project. It is necessary to understand the actual cement quality control practice of contractors. It is extension of earlier study.

OBJRCTIVES

The main objective of this study is to estimate 28 days strength based on 3 days & 7 days compressive strength of ordinary Portland cement.

LITERATURE REVIEW

Comparison between Indian Standard and Nepal Standard for OPC

Nepal Bureau of Standard and Metrology have published NS 49:2041 for 33 grade, NS 572:2076 for 43 grade & 53 grade of OPC. For 43 and 53 grade of cement, NBSM has published its standard recently in 2076 B.S, before this it provides approval only for 33 grade OPC to Nepali cement industries, so these industries mostly follow Indian standard for quality requirement of 43 and 53 grade OPC. Now NBSM has published standard for these grades of OPC. So, comparison between these standards becomes necessary. Table-1 and Table-2 shows the comparison between IS and NS.

Table-1: Comparison of Physical requirements for OPC between NS & IS

SN	Characteristics	Requirements					
		OPC 33		OPC 43		OPC 53	
		IS 269: 2015	NS 49: 2041	IS 269: 2015	NS 572: 2076	IS 269: 2015	NS 572:2076
i)	Specific Surface (Blain method), m2/kg, Min	225	225	225	225	225	225
ii)	Soundness:						
	a) By Le Chatelier method, mm, Max	10	10	10	10	10	10
	b) By autoclave test method, percent, Max	0.8	0.8	0.8	0.8	0.8	0.8
iii)	Setting time:						
	a) Initial, minutes, min	30	45	30	45	30	45
	b) Final, minute, max	600	600	600	600	600	600
iv)	Compressive strength, MPa (by keeping 1 day in air):						
	a) 72 ± 1 h, Min	16	16	23	23	27	27
	b) 168 ± 2 h, Min	22	22	33	33	37	37
	c) 672 ± 4 h, Min	33	33	43	43	53	53
	Max	48	48	58	58	-	-

Table-2: Comparison of Chemical requirements for OPC between NS & IS

SN	Characteristics	Requirements					
		OPC 33		OPC 43		OPC 53	
		IS 269: 2015	NS 49: 2041	IS 269: 2015	NS 572: 2076	IS 269:2015	NS 572: 2076
i)	Ratio of percentage of lime to percentages of silica, 0.66-1.02 alumina and iron oxide, when calculated by the formula: CaO – 0.7 SO_2/ 2.8 SiO_2 + 1.2 Al_2O_3 + 0.65 Fe_2O_3	0.66-1.02	0.66-1.02	0.66-1.02	0.66-1.02	0.80-1.02	0.80-1.02
ii)	Ratio of percentage of alumina to that of iron oxide, Min	0.66	0.66	0.66	0.66	0.66	0.66
iii)	Insoluble residue, percent by mass, Max	5.0	2.0	5.0	2.0	5.0	2.0
iv)	Magnesia, percent by mass, Max	6.0	5.0	6.0	5.0	6.0	5.0
v)	Total sulphur content calculated as sulphuric anhydride (SO_3), percent by mass, Max; If						
	Content of C_3A < 5%	3.5	2.5	3.5	2.5	3.5	2.5
	Content of $C_3A \geq$ 5%		3.0		3.0		3.0
vi)	Loss on ignition, percent by mass, Max	5.0	4.0	5.0	4.0	4.0	4.0

There are differences in initial setting time, insoluble residue, magnesia, sulphur content and loss on ignition in these IS and NS.

Initial setting time is minimum 45 minute given in NS considering that, it will allow enough time for transportation and placing of concrete before setting starts.

Insoluble residue (IR) in cement has non-cementing properties and does not play any key role in cement binding. The inertness of these materials leads to further increase of cement consumption to achieve design strength of concrete. IR percentage has no effect in normal consistency and setting times, however it affects early compressive strength of cement, as cement concrete gets older its impact in compressive strength is reduced.

To control setting time, 3-5% of gypsum is added with clinker before grinding & mixing in ball mill. Gypsum is calcium sulphate, which contribute in sulphur content in OPC. Gypsum when hydrated forms sulphur ions which delays hydration of C_3A components of cement. CA which has highest heat of hydration among all other Bogue's compound in cement brings quick setting of cement forming several minor cracks. Nepal is at higher elevation having which have mostly lower temperature and pressure, excess use of SO3 in cement cause slow setting and expansion of concrete. To avoid such situation, it has been limited to 3%.

Loss on ignition (LoI) of raw materials, cement or a clinker sample is the amount of weight lost through raising the temperature of the materials to a predetermined level. LoI in cement is due to presence of non-cementing or organic materials in the cement, presence of moisture or volatile matters, under-burnt materials due to insufficient burning of clinker. Hydration of cement is exothermic reaction and heat generated during hydration brings losses if LoI is present. This loss inside cement mortar or concrete mortar forms void internally. Presence of voids ultimately decreases its strength and concrete will be prone to seepage.

RESEARCH METHODOLOGY

a) Literatures (Publication, report, magazine, records, and data) of national international context were collected for the study regarding current issues of magnesia content and differences in Nepal standard and Indian standard.

b) Lab test result: Total five types of cement were chosen by random sampling. For each type of cement total twenty compressive strength test result were taken. All together one hundred compressive strength test result were collected from different from bachelor students project works.

Data Analysis

This study is mainly based on descriptive and analytical. For finding relation between 3, 7 & 28 - day compressive strength, data analysis using A to Z was used to carry out multiple linear regression analysis and determine best fit equation, required tests and validity of the equation. The model was tested at 95% confidence level to find best fit line. The reliability of regression model is measured by its goodness of fit, in-terms of coefficient of determination R^2 value. The expected equation for determining compressive strength of cement at 28 days ($F_{28\ days}$) was;

$$F_{28\ days} = C + A*X_1 + B*X_2$$

Where, A and B are coefficients corresponding to 3 days and 7 days compressive strength of cement respectively.

X_1 and X_2 are compressive strength of cement at 3 days and 7 days respectively. C is constant (intercept term).

RESULTS AND DISCUSSION

Estimation of 28 days compressive Strength

Regression Analysis

Multiple linear regression analysis was performed to determine the equation that best fit the relationship between 3 days, 7 days and 28 days compressive strength of cement. For this purpose, total 100 laboratories compressive strength test data of cement were selected for the analysis. Using data analysis results as shown in Table 3 to Table 4 was obtained.

Table-3: Summary output of regression analysis.

Regression Statistics	
Multiple R	0.887
R Square	0.788
Adjusted R Square	0.783
Standard Error	2.892
Observations	100

As shown in Table-3, the value of R^2 may be misleading in multiple linear regression models as the value of R^2 increases with the increase in explanatory variables. Therefore, for multiple linear regression analysis adjusted R^2 is defined. In this regression analysis, the adjusted R^2 value for the best fit equation is 0.783 which is close to 1. Thus, the fitted model is considered to be good one.

In regression, all Y values (dependent variable) cannot be same as predicted Y- values. Variability of Y values around the prediction line is measured by standard error of the estimate. When the predicted values and observed values are close, standard error is small. In this regression analysis, standard error is 2.892. Kothari & Garg [4] mentioned that the standard error is not a very good measure of judging goodness of fitted model. It should be considered along with coefficient of determination.

The standard error of estimate (S_e) can be interpreted as a standard deviation in the sense that, if there is normal distribution for the prediction errors, then it is expected about two- thirds of the data points to fall within a distance S_e above or below the regression line. Also, about 95% of the data values should fall within 2 times standard error ($2S_e$), and so forth [5]. In this study, out of 100 selected data, 73 data (more the two-third data points) fell within $\pm S_e$ and 97 data points (more than 95% of data values) as presented in appendix-1 fell within $\pm 2S_e$. Hence calculated standard error of 2.892 can be considered good for judging goodness of fitted model.

Thus, the fitted model is:
28 days compressive strength= 12.174 + 0.236 * 3 days strength + 0.864 * 7 days strength

From above equation consideration, weightage of constant value for 3 day is much less than that of 7 days. This is because of variations is more in 3 days than that of 7 days.

After knowing 3 days compressive strength of cement, for each one unit increase in 7 days compressive strength, 28 days compressive strength will be increased by 0.864.

Test of hypothesis (t-Test)

Table-4: Test of hypothesis (t-Test)

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	12.174	2.382	5.112	1.60E-06	7.447	16.900
3 days	0.236	0.116	2.043	0.04	0.007	0.466
7days	0.864	0.114	7.550	2.39E-11	0.637	1.091

We test for each explanatory variable X_j (j= 3 days and 7 days compressive strength of cement). For this, we set following hypothesis:

Null Hypothesis

H_0: $b_j = 0$ (no linear relationship between X_j and Y i.e. 3 days and 7 days compressive strength of cement are insignificant in establishing linear relationship with 28 days strength of cement).

Alternative Hypothesis

H_a : $b_j \neq 0$ (linear relationship between X_j and Y i.e. 3 days and 7 days compressive strength of cement are significant in establishing linear relationship with 28 days strength of cement).

Fifth column of Table 4, provides the p-value, the test of each individual explanatory variable as well as intercept. As we know, we compare p-value with some level of significance and reject the null hypothesis if p-value is smaller.

As shown in Table-4, p-values corresponding to intercept, 3 days and 7 days compressive strength of cement are all smaller than 0.05, therefore at 5% level of significance, we reject the null hypothesis that 3 days and 7 days compressive strength of cement are insignificant in establishing linear relationship with 28 days strength of cement in the model.

F-Test (ANOVA)

Table-5: ANOVA (F-Test)

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	3020.821	1510.411	180.576	1.99E-33
Residual	97	811.345	8.364		
Total	99	3832.166			

In case of multiple linear regression analysis, F-test is used to test the overall validity of the model or to test any of the independent variable is having linear relationship with the dependent variable. For this test, we set following hypothesis:

Null Hypothesis

H_0: $b_1 = b_2 = 0$ (no independent variable is significant i.e. 3 days and 7 days compressive strength of cement are insignificant)

Alternative Hypothesis

H_a: at least one $b_j \neq 0$ (at least one independent variable affects dependent variable linearly i.e. at least 3 days or 7 days compressive strength of cement affects 28 days strength of cement linearly) As shown in Table-5, significance F is the p-value of the test which is much more less than 0.05. Therefore, at 5 % level of significance, we reject the null hypothesis and conclude that at least one explanatory variable (either 3 days or 7 days compressive strength of cement) has significant linear relationship with response variable (28 days compressive strength of cement) and the fitted model is valid.

Test of Multicollinearity

Multicollinearity generated by an independent variable is measured by Variance Inflationary Factor (VIF) given by:

$$VI = \frac{1}{1 - R^2}$$

Where R^2 is the coefficient of determination of a liner regression model.

Kothari & Garg [4] mentioned if VIF is greater than 5, an independent variable is highly correlated with the other independent variables. In the above fitted model, 3 days compressive strength and 7 days compressive strength of cement is corelated. So it is necessary to test multicollinearity problem in the model.

Putting value of R^2=0.783 in above equation, we get VIF = 4.6 which is less than 5. Hence independent variables (3 days and 7 days compressive strength of cement) are not highly correlated.

Validity of the Fitted Model

Table-6 presents the Nepal Standard requirements for compressive strength of cement.

Table-6: Nepal Standard requirements for compressive strength of cement

Compressive strength in N/Sq.mm at age of	**NS 49: 2041 33 Grade**	**NS 572: 2076 43 Grade**	**NS 572: 2076 53 Grade**
a) 3 days	16 minimum	23 minimum	27 minimum
b) 7 days	22 minimum	33 minimum	37 minimum
c) 28 days	33 minimum	43-58	53 minimum

The fitted model is:
28 days compressive strength= 12.174 + 0.236 * 3 days strength + 0.864 * 7 days strength

The minimum 3 days and 7 days compressive strength of cement as mentioned in Table 4.4 was used in above fitted model to determine compressive strength of cement at 28 days and validated with minimum 28 days compressive strength as mentioned in Table 6 within standard error. The result is presented in Table-7.

Table-7: Calculated minimum compressive strength of cement at 28 days

Grade of cement	Required compressive strength at 28 days (N/mm^2) as per NS	Calculated 28 days compressive strength (N/mm^2)	Error
33	33 minimum	34.95	-1.95
43	43-58	46.11	-3.11
53	53 minimum	50.51	2.49

As shown in Table-7, calculated error in calculated 28 days compressive strength for 33 and 53 grade cement are within standard error. For 43 grade cement, although calculated error exceeds standard error slightly, the calculated compressive strength at 28 days is within range as requirement mentioned in Table-6.

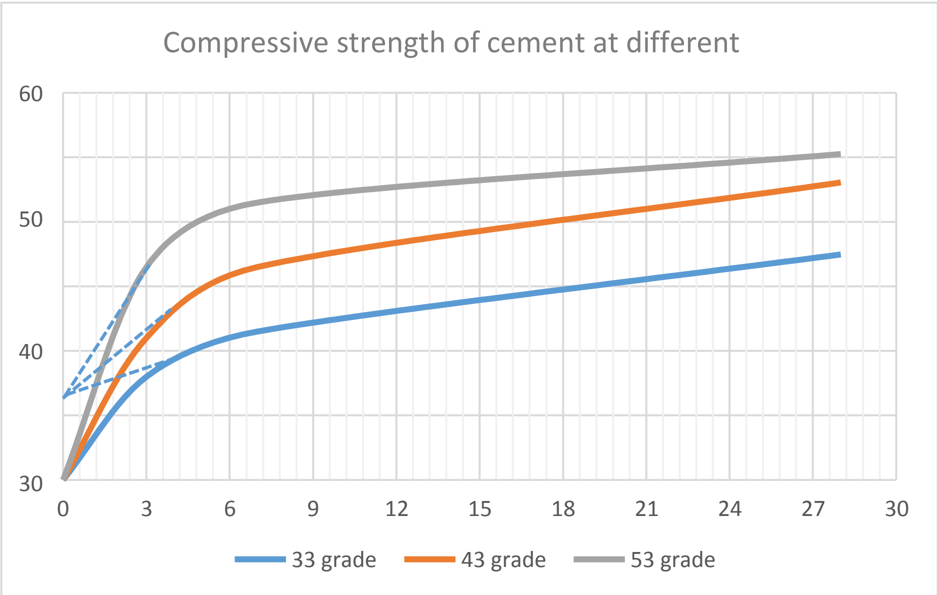

Fig-1: Compressive strength of cement at different age

The constant term in regression analysis is often defined as the mean of the dependent variable when all of the independent variables in the model are set to zero. In a purely mathematical sense, this definition is correct. Unfortunately, it’s frequently impossible to set all variables to zero because this combination can be an impossible or irrational arrangement. Generally, it is essential to include the constant term in a regression model. The reason is that it forces the residuals to have that crucial point zero. Furthermore, if the constant term is not included in regression model, the constant is actually set equal to zero. This action forces the regression line to go through the origin. In other words, a model that doesn’t include the constant requires all of the independent variables and the dependent variable to equal zero simultaneously [6].

Frost [6] mentioned that when it comes to using and interpreting the constant in a regression model, the constant in regression model should always be included even though it is almost never worth interpreting. The key benefit of regression analysis is determining how changes in the independent variables are associated with shifts in the dependent variable.

Figure-1 shows graph between minimum compressive strength at 3 days and 7 days of cement as mentioned in Table-6 and calculated compressive strength of cement at 28 days as mentioned in Table 7 for different grades of cement. As the analysis in this study is based only on strength of cement at 3 days, 7 days and 28 days, the curve shows the intercept is 12.174 which indicates the strength of cement at 0 days is 12.174 N/mm^2 when value of 3 days and 7 days strength of cement are kept zero which is just theoretical. But practically, 3 days and 7 days strength of cement can never be zero and intercept term is not worth interpreting and is just the projection of plot to Y-axis. However, strength of cement at 0 days just after casting might be zero. Hence the graph shows the projection of 3 days, 7 days and 28 days plot to zero at 0 days while depicting nearly linear relationship among 3 days, 7 days and 28 days strength of cement.

CONCLUSION

Linear relationship between 3 days, 7 days and 28 days compressive strength model was determined with adjusted R^2 value of 0.783. For this study, at 5% level of significance, it can be concluded that at least one explanatory variable (either 3 days or 7 days compressive strength of cement) has significant linear relationship with response variable (28 days compressive strength of cement) and the fitted model is valid. The fitted equation of analysis was 28 days compressive strength= 12.174 + 0.236 * 3 days strength + 0.864 * 7 days strength.

RECOMMENDATIONS

Contractors as well as clients of different project can use the determined relationship between compressive strength of OPC at different age to estimate 28 days compressive strength of cement from the strength obtained at 3 days and 7 days test.

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