Comparative Study on Statistical Quality Control of Concrete in Bhutanese Construction Industry as per the Specification of Indian Standards

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ABSTRACT

Bhutan is a fast-developing country and over the recent years has witnessed the constructions of many infrastructures. The Bhutanese construction industry has boomed and is one of the largest employing industries. Like most developing countries, the construction industry plays a dominant role in the socio-economic development of the country. There are various agencies set up to monitor the quality of works and formulate the construction guidelines to facilitate the well performing infrastructures in the country. Quality has always been concerning in any construction firm of any countries. Bhutanese engineers however are aided by various parameters of Indian standard code for design and execution of construction works. The paper presents some of the misinterpretation in quality checks and processes observed during authors tenure as project engineer of a construction works. The paper depicts the observation based on quality control in field which deviated from the Indian standard code and hope to throw the light on way the quality checks done for concrete works.

***Key Words:* Workability, Slump, Acceptance criteria, platen restraint, Quality control**

1. INTRODUCTION

The Ministry of Works and Human Settlement has initiated several reforms to streamline several policies, rules and regulations, and procedures to enhance and promote quality construction in the country(Works & Settlement, 2018).The national housing survey conducted in 2017 indicated around 37% of total houses in Bhutan as reinforced concrete structures(Chettri, Thinley, & Koirala, 2019). Furthermore, there is still rapid increase in construction activities using conventional concrete structures. This makes dispensable to make sure that these structures suffice the quality to perform itself in times of various disasters. Quality as expressed is essentially defined as totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs. Here, stated and implied needs basically refer to workmanship and integrity of people working to execute the construction activities(Minami, 2012). Therefore, the operational techniques and activities that are used to fulfil requirements for quality is the quality control. One must make sure that these operational activities are as per the technical guidance such as Indian standard, British and American. Bhutan however is must comfortable with varieties of IS code and its specification for most of the concrete structure both design and execution. Concrete has to be evaluated both fresh state as well as in hardened state. It was observed that there comes the paucity of understanding on how these operational activities to evaluate in both the states are performed most of the time. These deviation with respect to Indian standard code are presented in the paper.

2. OBSERVATION OF QUALITY CONTROL ACTIVITIES PERFORMED IN FIELD

Followings are some of the operational activities observed in the field. These are solely as per the observation noted by author and doesn't imply to all the projects in the country. However, the operational techniques explained below with respect to standards will serve to be essential for engineers, contractors and quality control implementing agencies.

1. Most of the time concrete casting is done without any test on the rheology of the material. In some large projects' workability test is conducted during the initial casting of footing pads and same material ingredients are used for the entire projects.
2. It was also observed that client enforces workability test during the construction of each structural elements i.e. a set of workability test during casting of footings, another set during columns followed by beam and slab.
3. Description stated in sequence number 1 plus a set of compressive strength test on a sample of cubes (three specimens).
4. Only compressive strength test on a sample of cubes (three specimens) taken from any structural element.
5. Only compressive strength test on a sample of cubes (three specimens) in all structural elements.
6. Description of sequence number 2 plus a set of compressive strength test on a sample of cubes (three specimens).
7. Description of sequence number 2 plus a set of compressive strength test on a sample of cubes (three specimens) in each structural element.

3. QUALITY CONTROL AS PER CODAL PROVISIONS.

Evaluation of quality of concrete has to be done in both fresh and hardened state before the casting of each structural elements. In its fresh state, quality of concrete is monitored using tests for workability like for example the slump test. In its hardened state, quality of concrete is monitored using tests for mechanical properties like compressive strength, modulus of rupture, splitting tensile strength etc. However, in low rise building, short span bridges, retaining walls and other reinforced structures compressive strength test is sufficient to streamline the quality.

3.1 Monitoring Concrete Quality in Fresh State

The ingredient composition in the concrete must be such that concrete must be of adequate workability in placing condition and can properly be compacted. IS 1199 (clause 7) must be checked for various degree of workability in different placing conditions along with its slump values(BIS:1199(1959), 1999). However, discrepancies arise in process and number of sampling for the test. For this, IS 4905-1968 methods for random sampling has to be strictly followed which do justice to the concrete mix of other batches and also provide reasonable degree of accountability to one who enforces quality control at that work(IS 4905-1968, n.d.). A random sampling procedure as specified in code has to be adopted to ensure that each concrete batch has reasonable chance of being tested.

For examples during the casting of slab of a buildings slump values noted randomly from the batch/mixer machine/lots are as follows: 76, 74, 70, 66, 78, 80, 86,75, 70, 68, 79, 80, 75, 69, 70, 74, 70, 68, 68, 70, 76, 75, 80, 70, 75, 68, 70, 75, 78,74, 68, 70, 75, 78, 80, 85, 85, 75, 70, 70, and 70 mm. *Which ones are accepted? This is determined using above mentioned code as follows:*

a. **First find mean of data set which is given by,**

$$\dot{X} = \frac{\sum_{i=1}^{n} Xi)}{n}$$

or

$$\dot{X} = \frac{1}{n}\sum Xi$$

or

$$\dot{X}=\frac{1}{n}(X_1+X_2+X_3+X_4+\cdots+X_n)$$

For the given example $\dot{X}$=75mm

b. **Next find the standard deviation of the data set,**

$$S=\sqrt{\frac{\sum_{i=1}^{n}(Xi-\dot{X})^2}{n-1}}$$

or

$$S = \sqrt{\frac{(X1-\dot{X})^2+(X2-\dot{X})^2+\cdots+(Xn-\dot{X})^2}{n-1}}$$

For the given example s=5.09mm

c. **Find coefficient of variation, C.o.V of the data set,**

$V = \frac{s}{\bar{x}}$ x 100

For the given example V= 6.9%

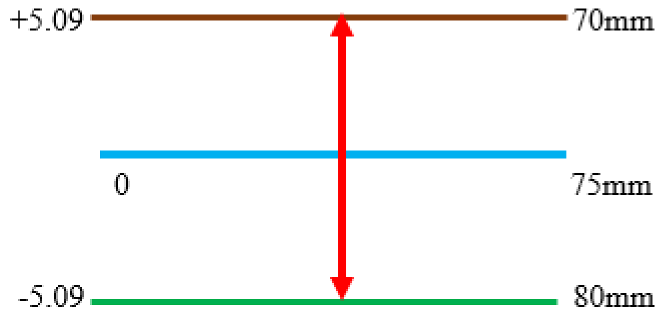

Figure 1: Limits of workability for above example

This implies that the acceptable range of the measured slump values is 75 – 5.09 = 69.91 or say 70 mm and 75 + 5.09 = 80.09 or say 80 mm. Hence, measured average slump values less than 70 mm or more than 80 mm should invite corrective action. The Coefficient of Variation, C.o.V. = (5.09/74) x 100 = 6.9% which corresponds to 'good' level of quality control ($\leq$ 15%).

3.2 Monitoring Concrete Quality in Hardened State

This essentially concerns to compressive strength test. IS 4905-1968 methods for random sampling has to be followed to randomly chose the samples and table 1 gives the number of samples to be collected.

Quantity of concrete in a particular work (m^3)	Number of samples (note that 1 sample has 3 specimens)
1-5	1
6-15	2
16-30	3
31-50	4
51+	4 plus one additional sample for each additional 50m^3 or part thereof

Table 1: Number of samples as per IS 456-2000(Bureau of Indian Standard(BIS), 2000)

For example, Let the total volume to be concreted at one go = 110 m. Hence, number of samples required for 28-day strength testing= 4+1+1 = 6. Hence, number of cubes to be collected for 28-day strength testing = 6 x 3 = 18. If early age strength testing has to be done, then an additional 18 cubes have to be collected for 7-day strength testing. Therefore, total number of cubes required to be collected for strength compliance= 18 + 18 =

36. However, question still arises how to do the random sampling. IS 4905-1968 presents different types of random sampling (i.e. simple random sampling, stratified random sampling, systematic random sampling, cluster random sampling and two stage random sampling). The example below explains the simple random sampling.

For example, 50 m³ of concrete has to be deposited in one continuous operation in 10 batches of 5 m³. An example of simple random sampling is demonstrated here for M20 concrete grate. Number of samples required for 28-day strength testing = 4. Let the 4 samples be collected from 4 different concrete batches.

10 batches of concrete (each batch =5m³)									
									
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Table 2: Representation for above example

From which machine will the four randomly selected samples have to be collected? Here, N, population size = 10. Sample size(M) = 4. Consider the following table of random numbers from IS 4905-1968. Now, samples (consisting of three specimens) from which truck has to be collected? Consider any starting point in the table. Pick up any four (M=4) numbers whose last two digits (since N=10 i.e. it has 2 digit. If N=200 then chose last 3 digit) are between 0 and 10. Repetitions are not allowed in the selected numbers. Follow the table below:

	75	64	26	45	10	79	18	58	61	09	67	05	60	19	91	14	62	02	35	98	88	51	53	56	96
Starting point	24	05	89	42	27	98	62	31	19	95	24	25	58	50	49	19	30	31	58	59	49	47	85	48	30
	63	18	80	72	41	26	11	91	96	81	55	92	44	23	93	97	89	53	40	80	29	46	34	39	63
	38	81	93	68	22	84	92	59	82	80	26	94	73	71	45	63	84	68	44	94	93	64	13	94	31
	25	59	54	43	02	16	41	97	40	65	70	29	77	74	27	69	81	70	01	95	82	99	77	80	21
	12	28	15	88	98	21	28	92	06	08	33	72	05	13	06	85	65	33	90	20	92	33	27	59	49
	36	59	95	67	96	25	72	30	41	81	71	92	18	65	17	64	58	56	89	28	69	18	36	06	71
	91	72	83	68	11	22	20	15	01	65	34	60	47	16	09	44	45	46	97	83	44	51	98	67	29
Sample no. 2	86	04	[illegible]	43	69	12	85	04	93	74	80	08	57	25	79	72	96	07	57	40	82	62	68	60	73
Sample no. 3	01	05	55	97	77	96	64	98	62	49	07	19	63	46	66	77	98	80	54	60	97	32	83	74	80
	26	95	96	93	87	17	59	90	35	94	73	68	03	27	29	49	64	66	14	65	57	24	45	76	39
	45	27	71	62	05	71	18	32	42	91	25	66	46	49	71	67	11	25	23	12	41	47	99	66	01
Sample no. 4	74	07	90	20	25	05	52	65	84	92	87	57	95	37	83	85	45	22	56	26	10	28	04	88	49
	77	99	91	43	02	96	06	07	36	68	17	48	06	09	84	31	86	91	87	96	63	87	32	33	70
	75	53	85	46	41	21	95	85	61	46	94	18	78	39	47	19	60	48	15	59	68	79	42	09	67
	45	65	84	36	28	48	33	82	62	71	74	48	75	92	34	32	94	26	70	88	35	50	19	97	52
	81	74	60	90	46	13	51	24	54	55	45	54	12	90	99	44	68	86	71	58	27	51	81	11	77
	95	11	06	85	83	93	53	74	52	97	79	53	21	41	44	45	81	02	38	07	38	07	80	89	56
	29	40	62	33	86	67	95	43	41	89	05	52	17	31	13	82	61	78	57	40	84	39	57	63	78
	79	14	32	21	09	32	27	02	70	20	61	47	24	42	76	77	27	99	36	15	36	98	08	40	53
	51	46	23	17	11	93	35	70	37	86	26	23	64	88	17	17	78	95	93	83	65	23	90	78	55
	98	75	60	99	89	91	18	20	27	74	31	82	01	32	97	97	43	21	87	82	33	28	10	56	98
	15	97	42	56	79	08	58	79	40	31	37	19	20	58	41	41	86	66	54	45	08	76	89	86	32
	06	16	35	93	26	36	97	26	17	71	74	95	89	08	50	50	62	48	46	26	24	95	93	01	64
	54	43	55	21	74	47	59	75	03	57	63	38	02	51	77	77	76	65	08	92	72	29	35	06	85
	66	31	33	83	19	15	01	38	69	66	77	83	67	16	45	04	07	72	32	08	53	91	03	48	49
No repetitions	06	07	88	09	61	19	29	39	18	16	76	48	53	81	12	61	39	87	60	33	84	75	78	22	55
Sample no. 1	57	01	84	02	27	11	14	47	20	44	22	34	90	86	79	89	68	71	46	77	08	76	89	86	32
	[illegible]	08	89	24	85	87	13	48	68	94	07	70	88	03	36	75	92	73	05	56	62	37	77	34	42
	17	05	93	51	30	82	49	61	45	31	91	55	23	11	89	53	15	34	76	76	33	41	99	79	43
	15	19	85	03	11	81	76	26	77	13	73	75	64	47	85	08	61	70	03	25	90	92	94	98	97
	91	64	24	16	46	23	44	70	47	17	10	70	43	35	56	67	73	71	90	57	37	34	54	95	35
	70	09	43	21	61	24	74	07	96	33	08	42	19	74	12	09	27	77	23	17	93	43	14	38	15
	62	94	51	92	60	49	25	15	85	34	86	09	11	03	96	47	54	02	32	76	75	13	76	32	03
Select the first sample of 3 cubes from truck no. 1	53	13	59	22	82	87	37	94	62	65	16	40	14	38	71	41	55	14	50	28	62	74	08	31	58
	93	59	48	96	88	04	83	14	84	53	45	70	37	18	05	79	14	45	55	46	28	55	36	35	77
	58	14	07	89	30	51	76	38	05	32	13	01	23	63	33	24	73	13	21	16	46	78	20	67	32
	47	40	60	22	29	52	16	70	44	19	46	41	93	73	78	68	88	42	02	28	66	17	83	37	38
	28	02	81	52	80	56	08	63	06	22	35	50	32	75	22	66	69	65	97	35	87	65	33	29	10
	69	24	61	41	42	24	73	45	55	46	47	21	95	09	62	86	67	29	74	54	95	14	74	72	79

Table 3: Random sampling table from IS 4905-1968.

There as indicated in table 3, three specimens each from truck number 1, 4, 5 and 7 are chose to cast the cubes. Their 28 days compressive strength test are done. It clearly shows that each of the 10 trucks had reasonably equal degree of getting selected preventing injustice and discrepancies. This also tackles manipulation by engineers and contractors. Such process gives good accountability from quality control authority.

4 Randomly selected batches are:									
									
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Table 4: Selected batch for above example

3.3 Interpretation of 28 days Characteristics Strength test Result

The sample collected as in the process discussed above are tested during 7 days or 28 days depending on the need at site. However, during the filling the cube mould with sample IS 516-1959, Methods of test for strength of concrete has to be followed. The clause 2.10 explains about the two methods of compaction namely compaction by hand and by vibrator. Site engineer must be aware that improper compaction leads to significant strength reduction. The procedure for later is quite known to all filed engineer whereas for the first following (from IS 516-1959) has to be noted:

"2.10.1 Compacting by Hand — When compacting by hand, the standard tamping bar shall be used and the strokes of the bar shall be distributed in a uniform manner over the cross-section of the mould. The number of strokes per layer required to produce specified conditions will vary according to the type of concrete. For cubical specimens, in no case shall the concrete be subjected to less than 35 strokes per layer for 15cm cubes or 25 strokes per layer for 10cm cubes. For cylindrical specimens, the number of strokes shall not be less than thirty per layer. The strokes shall penetrate into the underlying layer and the bottom layer shall be rodded throughout its depth. Where voids are left by the tamping bar, the sides of the mould shall be tapped to close the voids."

Also, to note the clause 3 (particularly 3.3) and clause 5.5 from IS 516-1959 which describes about the precaution taken during curing of the cubes and process involved in placing the specimen in testing machine respectively. To maintain the good flow of the aspects of results interpretation for readers, let's assume that the samples collected from above batch i.e. batch 1, 4, 5 and 7 are tested (let's consider grade of concrete =M20) and results obtained are as follows:

Sample no.	Sample identification (date of casting)	Date of testing	Cube no.	Mass(kg)	Max. Stress (MPa)		Limit of acceptance (MPa)
					Individual	Average	
1 (batch 1)	Concrete cube (01/11/2019)	28/11/2019	1	8.22	20.4	20.13	0.85*Avg.=17.11
			2	8.20	19.8		1.15*Avg.=23.15
			3	8.25	20.2		(accepted)
2 (batch 4)	Concrete cube (01/11/2019)	28/11/2019	1	8.23	20.2	20.27	0.85*Avg.=17.23
			2	8.22	20.5		1.15*Avg.=23.31
			3	8.26	20.1		(accepted)
3 (batch 5)	Concrete cube (01/11/2019)	28/11/2019	1	7.99	16.5	19.93	0.85*Avg.=16.94
			2	8.23	20.6		1.15*Avg.=22.92
			3	8.22	22.7		(rejected)
4 (batch 7)	Concrete cube (01/11/2019)	28/11/2019	1	7.90	18.9	20.60	0.85*Avg.=17.51
			2	8.24	20.7		1.15*Avg.=23.69
			3	8.25	22.2		(rejected)

Table 5: Example to show ±15% variation

From table 5 it must be noted that clause 15.4 (to control results variation with the specimen) of IS 456 is respected which clearly mentions that characteristics compressive strength of each specimen must be within the limit ±15 % of the average (those specimens out of the limit in above example is highlighted in table 5). The cognizable weight of each cube must be 8.25kg (i.e. $0.15^3 *24*1000/9.81$). Any cube with lesser weight shows the improper compaction and gives lower strength as shown in table 5. Once the internal variation of specimens is determined the acceptability criteria must be imposed on all the samples. The acceptance criteria is given in IS 456-2000 clause 16 in table 11. The criteria table is shown below in figure 2:

Specified Grade	Mean of the Group of 4 Non-Overlapping Consecutive Test Results in N/mm²	Individual Test Results in N/mm²
(1)	(2)	(3)
M 15	$\geq f_{ck} + 0.825 \times$ established standard deviation (rounded off to nearest 0.5 N/mm²) or $f_{ck} + 3$ N/mm², whichever is greater	$\geq f_{ck} - 3$ N/mm²
M 20 or above	$\geq f_{ck} + 0.825 \times$ established standard deviation (rounded off to nearest 0.5 N/mm²) or $f_{ck} + 4$ N/mm², whichever is greater	$\geq f_{ck} - 4$ N/mm²

NOTE—In the absence of established value of standard deviation, the values given in Table 8 may be assumed, and attempt should be made to obtain results of 30 samples as early as possible to establish the value of standard deviation.

Figure 2: Acceptance criteria from IS 456-2000

Due to the problems of practical feasibility the table 11 of IS 456-2000 was amended and the given in amendment 4 as shown in figure 3.

Specified Grade	Mean of the Group of 4 Non-Overlapping Consecutive Test Results in N/mm² *Min*	Individual Test Results in N/mm² *Min*
(1)	(2)	(3)
M 15 and above	$\geq f_{ck}$ + 0.825 x established standard deviation (rounded off to nearest 0.5 N/mm²) or f_{ck} + 3 N/mm², whichever is greater	$\geq f_{ck}$ - 3 N/mm²

NOTES

1 In the absence of established value of standard deviation, the values given in Table 8 may be assumed, and attempt should be made to obtain results of 30 samples as early as possible to establish the value of standard deviation.

2 For concrete of quantity up to 30 m³ (where the number of samples to be taken is less than four as per the frequency of sampling given in 15.2.2), the mean of test results of all such samples shall be f_{ck} + 4 N/mm², minimum and the requirement of minimum individual test results shall be f_{ck} – 2 N/mm², minimum. However, when the number of sample is only one as per 15.2.2, the requirement shall be f_{ck} + 4 N/mm², minimum.

Figure 3:Acceptance Criteria-Amendment No. 4

In order to explain the acceptance criteria of IS 456-2000, following examples is tabulated (with assumed values) as per new amendment 4:

<table>
<tr><th>Sample no.</th><th>Group no.</th><th>Avg. compressive strength of 3 cubes (MPa)</th><th>Mean of 4 non overlapping consecutive test results</th><th>Standard deviation (Sd) up to last sample of the group</th><th>F_{ck}+3</th><th>F_{ck}+0.825*S_d</th><th>F_{ck}-3</th><th>Remark</th></tr>
<tr><td>1</td><td rowspan="4">1</td><td>23.00</td><td rowspan="4">24.125</td><td rowspan="4">IS 456-2000, Table 8S_d for M20=4</td><td rowspan="4">23</td><td rowspan="4">23.3</td><td rowspan="4">16</td><td>Accepted</td></tr>
<tr><td>2</td><td>25.00</td><td>Accepted</td></tr>
<tr><td>3</td><td>24.50</td><td>Accepted</td></tr>
<tr><td>4</td><td>24.00</td><td>Accepted</td></tr>
<tr><td>5</td><td>2</td><td>21.20</td><td></td><td></td><td></td><td></td><td></td><td>rejected</td></tr>
</table>

6		21.00	21.450	4	23	23.3	16	rejected
7		21.50						rejected
8		22.10						rejected
9	3	25.88	23.41	4	23	23.3	16	Accepted
10		25.89						Accepted
11		25.98						Accepted
12		15.89						rejected

Table 6: Example to demonstrate acceptance criteria as per IS 456-2000

Note that results shown in table does not fulfil the acceptance criteria (although it fulfils internal variation of ±15%) and therefore has to be discarded. Following example will illustrate the acceptance criteria as per IS 456-2000

For the construction of multi-level RCC parking in Phuentsholing M30 grade of concrete is mix designed with standard deviation of 3MPa. The compressive strength of 24 samples (72 specimens) and satisfying the ±15% internal variations are given in below. Apply IS 456:2000 acceptance criteria to the test results.

28.00,29.77,31.10,27.13,30.27,29.80,27.33,30.07,26.57,27.73,28.10,28.03,30.70,29.23,30.47,25.57,36.27,35.40,34.10,31.93,32.60,34.47,31.10,33.50

<u>Application of Acceptance criteria</u>

Total number of samples=24

Group of 4 non overlapping consecutive samples=

Group no.	1	2	3	4	5	6
Non overlapping consecutive samples	28.00,29.77,31.10,27.13	30.27,29.80, 27.33,30.07	26.57,27.73, 28.10,28.03	30.70,29.23, 25.57,36.27	36.27,35.40, 34.10,31.93	32.60,34.47, 31.10,33.50
Mean	29.00	29.37,	27.61	28.99	34.43	32.92

Table 7: Application of Acceptance criteria for above example

Acceptance criteria for individual test result (Amendment 4, IS 456-2000); Fck-3 i.e. 30-3 = 27MPa. Therefore, group 3 and 4 are rejected.

Acceptance criteria for group test result (Amendment 4, IS 456-2000); F_{ck}+3 i.e. 30+3= 33MPa and F_{ck} + 0.825*S_d i.e. 30+0.825*3= 32.475MPa.

Therefore, concrete of group 5 is acceptable. In the final cube or cylinder test result interpretation, one must know the multiplying factor to interchange their respective results. For the same concrete mixture, due to the effect of platen restraint and Saint-Venant's principle, cube strength will always be larger than cylinder strength. Cylinder strength = 0.80 times the cube crushing strength

4. CONCLUSION

Construction Industry plays a major role in the economic growth of a nation and occupies a pivotal position in the nation's development plans. Monitoring specific project result to determine if they comply with relevant quality standards and identifying ways to eliminate cause of unsatisfied performance. Contract documents comprise a clear, complete, and accurate description of the facility to be constructed, correctly conveying the intent of the owner regarding the characteristics of the facility needed to serve his or her purposes(Chahal & Emerson, 2007). The important aspects for any man-made structure are strength, serviceability and durability of the structure. To achieve these aspects, the use of standard quality materials is of prime importance. All the materials that are to be used in the construction must undergo certain tests to qualify the quality requirements as per standard codal provisions. Quality control ideally concerns on examining the structures materials and specifications for the construction. Quality control is management system that ensures materials whether the provided comply with the requirements such as being dependable, satisfactory and safe Strong quality control measures are basic needs of any structures in providing better serviceability of the project, durability and stability of project lifespan. It was observed that there were number of cases where the strict codal provisions were not respected in Bhutanese construction scenario. Authors have considered the guidelines prescribed in the Indian standard codes and presented in the paper in the hope to help field engineer to monitor the quality aspects rationally. The technical procedures for workability and compressive strength test are elaborated with suitable examples to enable the reader to correlate the codal guidelines. Any discrepancies with respect to any clause and examples can be directly discussed with the authors.

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DEAR MADAM,

KINDLY ACCEPT THIS PAPER FOR PUBLICATION. IT MAINLY FOCUSES ON QUALITY CONTROL DEVIATION WHICH WAS OBSERVED DURING MY TENURE AS PROJECT ENGINEER. IT ESSENTIALLY HIGHLIGHTS THE CODAL PROVISION THAT MUST BE RESPECTED DURING THE CONSTRUCTION AND QUALITY CONTROL. IT AIMS TO HELP FILED ENGNEER AND QUALITY CONTROL AUTHORITY AS WEL AS CONTRACTORS.
KINDLY LET ME KNOW ANY DISCREPANCIES.

THANK YOU