Quality Conference – 2010

QUALITY ENGINEERING USING TAGUCHI DESIGN IN CONCRETE MIXTURES DESIGN

By

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Presentation Outline

- ❑ Objective
- ❑ Introduction
- ❑ Experimental work
- ❑ Analysis Results
- ❑ Discussions
- ❑ Conclusions
- ❑ Recommendations

Objective of Study

The objective of this study is to use the Experimental Design as one of the modern practical scientific methods to identify the significant concrete mixtures design parameters and to determine the optimal parameter settings which would give the maximum compressive strength.

Introduction

Identifying Quality

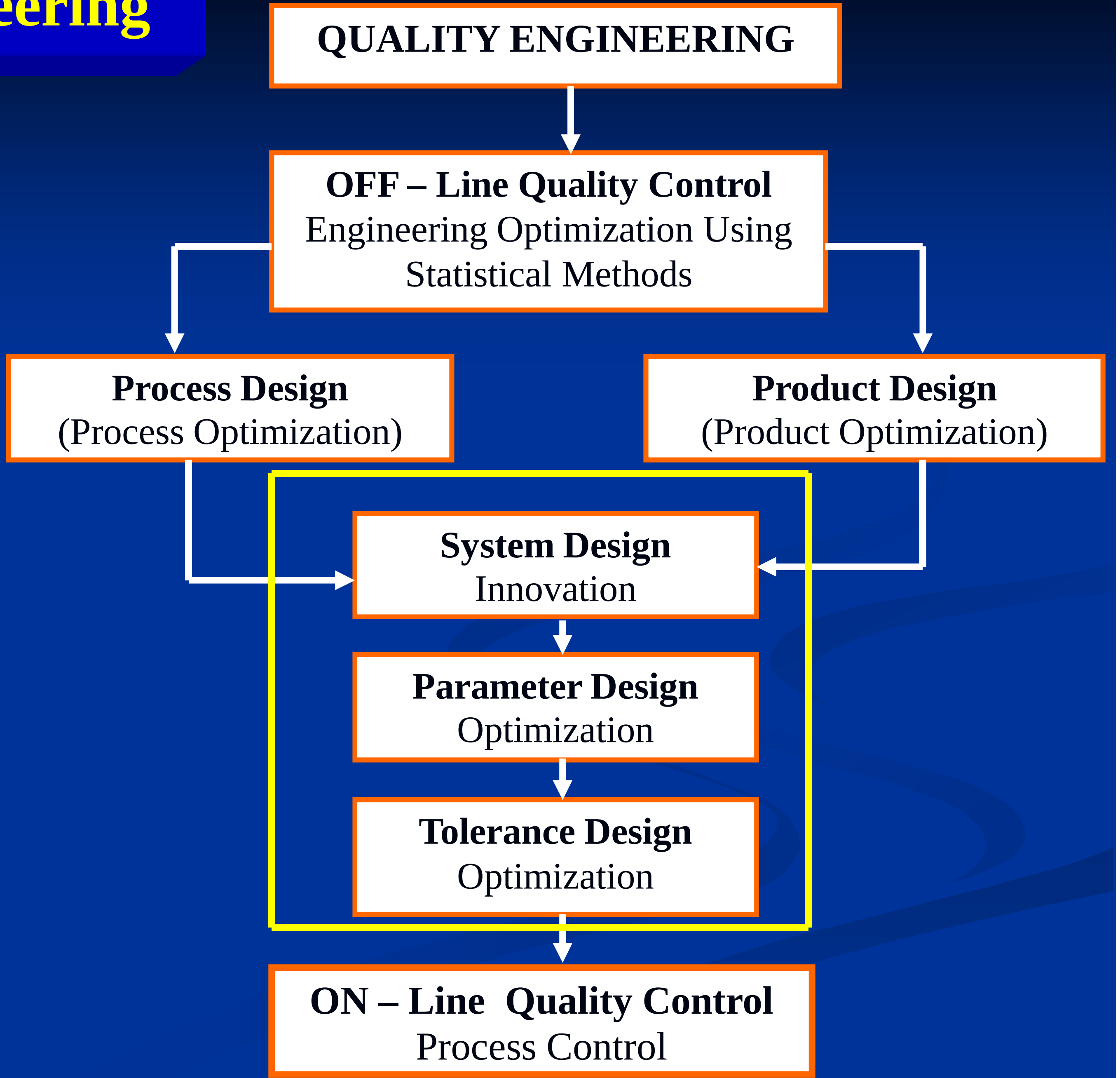
1. Customer Oriented (Mainly Customer Requirements)

2. Producer Oriented

3. Both Customer and Producer Oriented

4. Both Customer and Producer Oriented Including the Environmental and Safety Dimensions

Quality Engineering



Robust Design

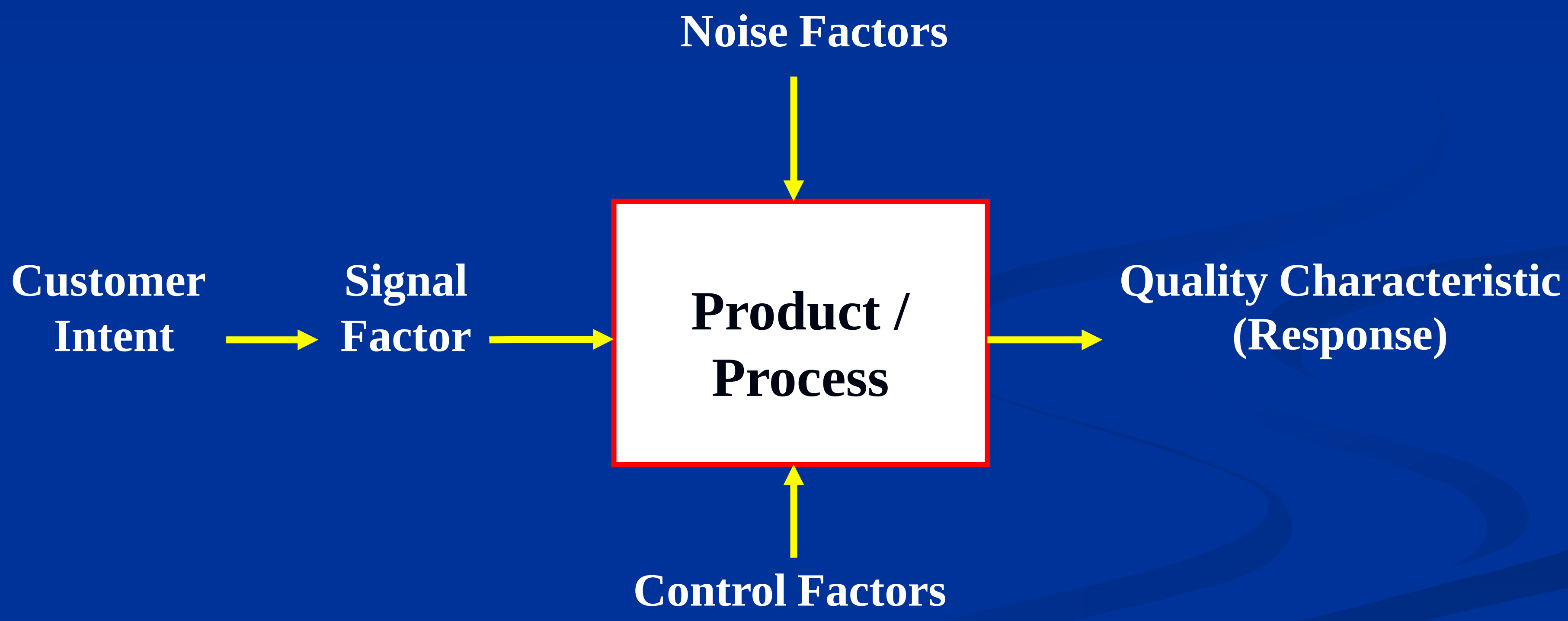
Robust design is defined as an engineering methodology for improving productivity during research and development so that high – quality products can be produced quickly and at low cost.

Robust Design Tools

- Classification of Parameter
- Quadratic Loss Function
- Signal-to-Noise Ratio

Classification of Parameter

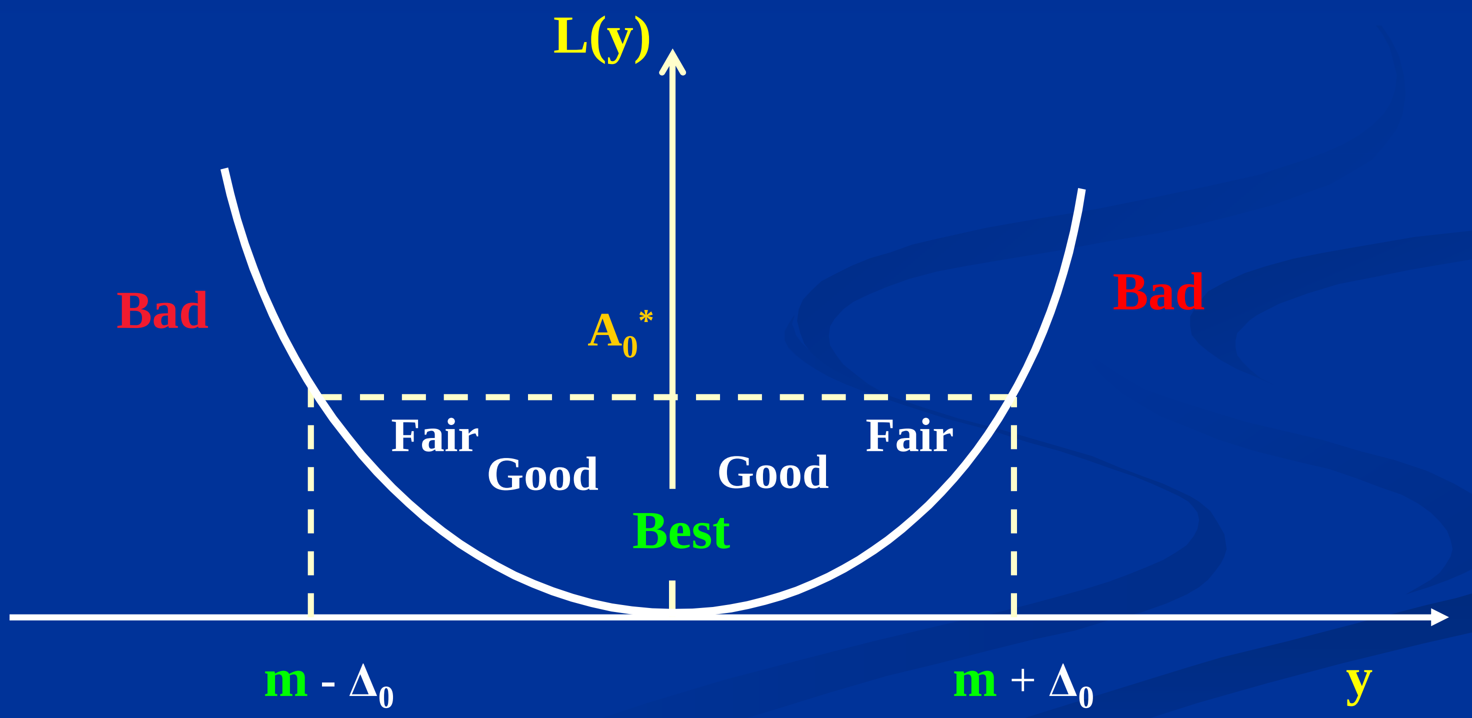
P Diagram used to classify the variables associated with the product into noise, control, signal (input), and response (output) factors.



The System P- Diagram

2. The Quadratic Loss Function

The loss increases slowly when the quality y is near m , but as it goes further from m the loss increases more rapidly.



Signal-To-Noise (S/N) Ratio

SNR is the ratio of the mean (signal) to the standard deviation (noise) .

Three Standard Types of SNR

1. Smaller The Better

$$SNR_{STB} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} R_{ai}^{2}\right)$$

2. Nominal The Best

$$SNR_{NTB} = 10\ \log\left(\frac{\overline{R}_{a}^{2}}{S^{2}}\right)$$

3. Larger The Better

$$SNR_{LTB} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{R_{ai}^{2}}\right)$$

Experimental Work

The Application of Experimental Design in Concrete Mixtures Design

Quality Control of Materials used in Concrete Mixtures

1. Cement

Results of the Physical and Mechanical Analysis of Normal Portland Cement (Zletin cement)

No.	Test		Results	Libyan standard Limits No. 340/ 09	Remarks
1	Initial setting time (minutes)		185	min 45	(√)
2	Final setting time (hours)		4 : 35	max 10	(√)
3	Soundness (mm)		1	max 10	(√)
4	Fineness (cm^2/g)		2531	min 2500	(√)
5	Compressive strength (N/mm^2)	3 days	25	min 21	(√)
		28 day	55	min 39	(√)

The Results of the Chemical Analysis of Normal Portland Cement (Zletin cement)

No.	Constituent	Results (%)	Libyan Standard Limits No. 340 / 09 (Maximum Limit)	Remarks
1	L.O.I	2.109	3.0	(√)
2	I.R	0.760	1.5	(√)
3	SO_3	2.122	2.5	(√)
4	MgO	1.607	5.0	(√)
5	CL	0.0048	0.1	(√)
6	C_3S	37.390	-	-
7	C_2S	32.790	-	-
8	C_3A	7.901	-	-

2. Aggregates

Results of the Physical, Mechanical and Chemical Analysis for Coarse Aggregates & Fine Aggregate (Zletin sand)

No.	Test	Results			Libyan Standard Limits No. 49-2002	Remarks
		Coarse Agg N0. I	Coarse Agg N0. II	Sand		
1	**Fine materials (%)**	1.65	0.68	1.20	4 % max .	(√)
2	**Specific gravity**	2.644	2.661	2.700	2.5 – 2.7 as a natural range	(√)
3	**Water absorption (%)**	1.45	1.14	0.14	3 % max .	(√)
4	**Impact value (%)**	18.64		-	45 % max .	(√)
5	**Crushing value (%)**	19.65		-	45 % max .	(√)
6	**10 % fines value (KN)**	178.00		-	50 KN min .	(√)
7	**Chloride content CL (%)**	0.0075	0.0036	0.0076	0.05 % max .	(√)
8	**Sulphate content SO_4 (%)**	0.180	0.240	0.195	0.5 % max .	(√)

3. Mixing Water

Results of the Chemical Analysis of Used Water

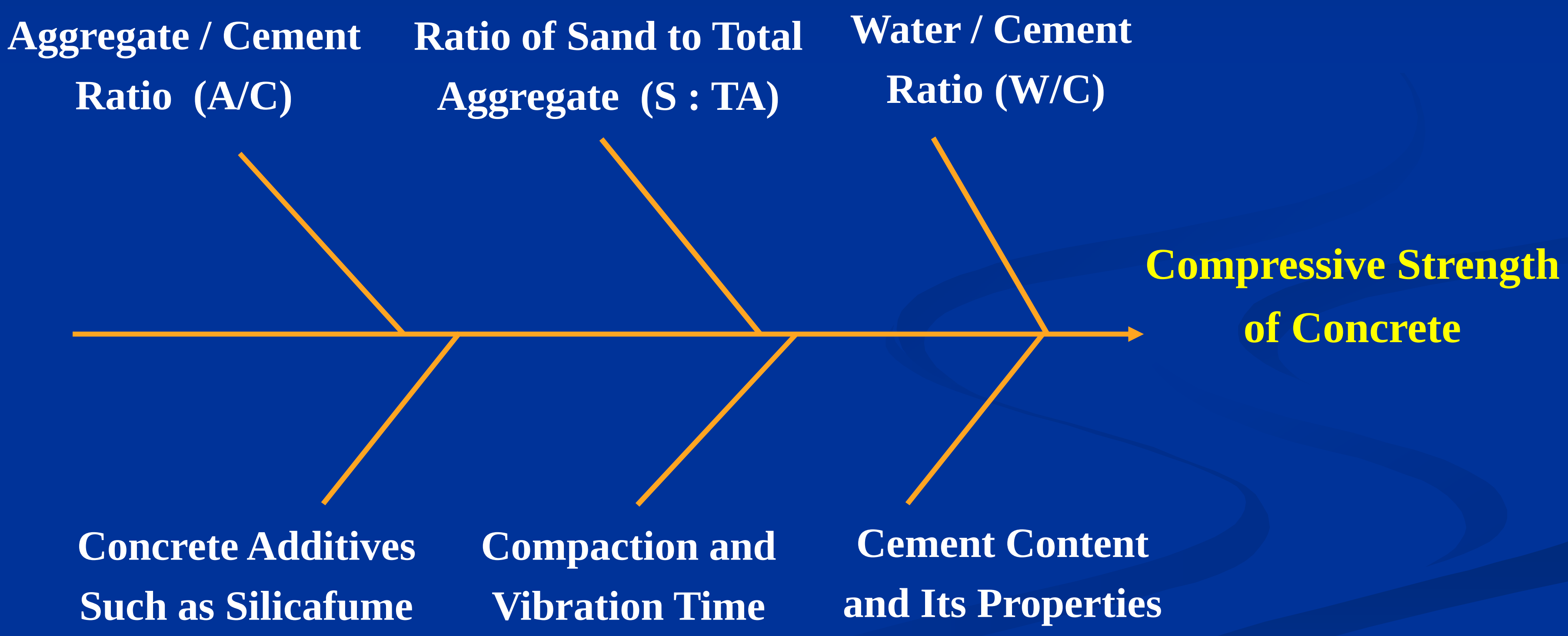
No.	Test	Results	Libyan Standard Limits No. 294 – 1988 (Maximum Limit)	Remarks
1	T.D.S	1031.00	2000 mg per liter	(√)
2	PH value	8.00	6-8	(√)
3	Chloride content CL	354.53	500 mg per liter	(√)
4	Sulphate content SO_4	532.00	1000 mg per liter	(√)
5	Alkali carbonates and bicarbonates	425.00	1000 mg per liter	(√)

4. Admixtures

1. Superplasticizer (Sikament 163)

2. Silicafume

Cause and Effect Diagram for the Factors Affecting the Compressive Strength of Concrete



Procedures and Steps of Taguchi Parameter Design

Step 1 Selection of the Quality Characteristics

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Step 2 Selection of the Control Factors

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Step 3 Selection of Orthogonal Array (OA)

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Step 4 Conducting the Experimental work

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Step 5 Analysis Results and Determining of Optimum Design Parameters

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Step 6 Predicted Values of Optimum Performance

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Step 7 Confirmation Run

Step 1: Selection of the Quality Characteristics

- **Identify The Optimum Compressive Strength in Concrete Mixtures.**
- **The Largest Value is The Best.**
- **A larger-The-Better Quality Characteristic.**

Step 2 : Selection of the Control Factors

Control Factors and Levels

Factors	Abbreviations & units	levels		
		1	2	3
Water / Cement ratio (A)	(W/C) %	0.45	0.52	0.59
Sand ratio to Total Aggregate (B)	(S:TA) %	0.30	0.35	0.40
Silicafume (C)	(Sf) %	0.04	0.07	0.10

Step 3 : Selection of Orthogonal Array (OA)

Three factors were studied in this research, and three levels of each factor were considered. So,

$$L_{27}\ (3^3)$$

Orthogonal Array was selected.

Step 4 : Conducting the experimental work

Each run is conducted four times and are indicated as (R_1, R_2, R_3 and R_4). Hence, a total of (27 × 4) = **108** data values were conducted.

$$SNR_{LTB} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{R_{ai}^2}\right)$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-1}}$$

$$L = k\left[\frac{1}{\bar{y}^2}\right]\left\{1+\left(\frac{3\times SD^2}{\bar{y}^2}\right)\right\}$$

$$\overline{R}_{ai} = \frac{1}{n}\sum_{i=1}^{n} R_{ai}$$


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AUTOTEST

Experiment Runs and Data Calculation for Concrete Mixtures Design

Run No.	Factors			Response: Compressive Strength R_a (MPa)				Mean (MPa)	Standard Deviation	Variance	SNR (dB)	Loss Function ($)
	W/C Ratio (A)	S :TA Ratio (B)	Sf Ratio (C)	R_1	R_2	R_3	R_4					
1	0.45	0.30	0.04	53.53	53.22	54.85	53.22	53.71	0.777	0.604	34.598	0.000347
2	0.45	0.30	0.07	59.00	60.25	60.05	61.15	60.11	0.883	0.779	35.577	0.000277
3	0.45	0.30	0.10	64.90	65.50	65.71	66.07	65.55	0.490	0.240	36.330	0.000233
4	0.45	0.35	0.04	53.22	54.77	55.85	55.09	54.73	1.105	1.222	34.761	0.000334
5	0.45	0.35	0.07	56.2	56.35	57.55	57.42	56.88	0.703	0.495	35.098	0.000309
6	0.45	0.35	0.10	61.65	62.51	60.34	60.69	61.30	0.980	0.960	35.746	0.000266
7	0.45	0.40	0.04	50.41	50.26	51.82	50.29	50.70	0.753	0.567	34.097	0.000389
8	0.45	0.40	0.07	54.70	55.13	56.93	55.71	55.62	0.968	0.937	34.901	0.000324
9	0.45	0.40	0.10	60.29	59.94	59.30	61.75	60.32	1.038	1.077	35.606	0.000275
10	0.52	0.30	0.04	50.43	51.39	50.48	52.43	51.18	0.941	0.886	34.179	0.000382
11	0.52	0.30	0.07	51.40	52.70	53.84	52.55	52.62	0.998	0.996	34.420	0.000362
12	0.52	0.30	0.10	56.39	56.53	55.25	55.06	55.81	0.760	0.577	34.932	0.000321
13	0.52	0.35	0.04	48.43	47.39	48.20	46.90	47.73	0.711	0.505	33.574	0.000439
14	0.52	0.35	0.07	51.51	52.93	53.20	53.00	52.66	0.775	0.601	34.428	0.000361
15	0.52	0.35	0.10	54.22	55.26	55.43	54.08	54.75	0.696	0.484	34.766	0.000334

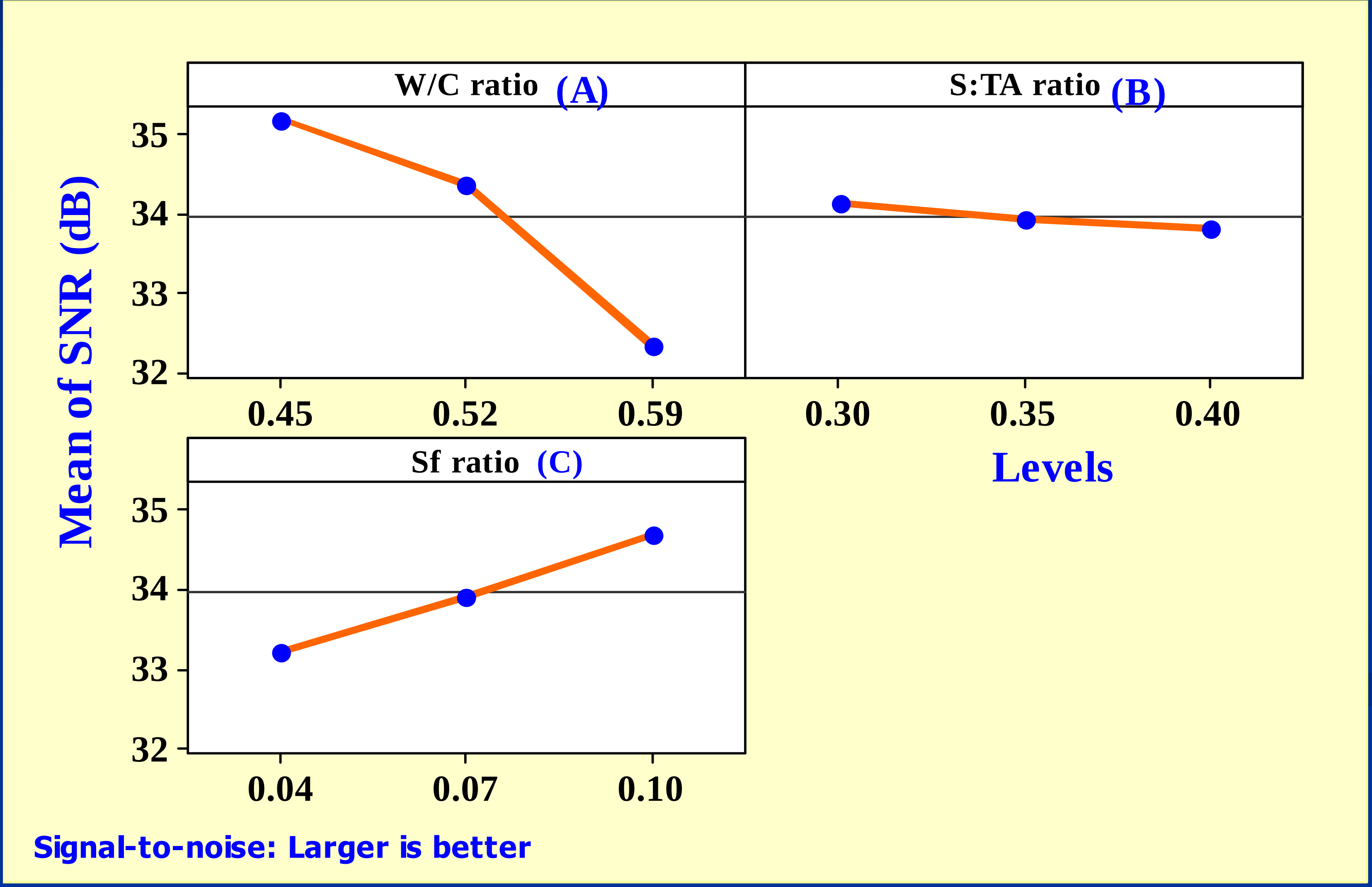
Run No.	Factors			Response: Compressive Strength R_a (MPa)				Mean (MPa)	Standard Deviation	Variance	SNR (dB)	Loss Function ($)
	W/C Ratio (A)	S :TA Ratio (B)	Sf Ratio (C)	R_1	R_2	R_3	R_4					
16	0.52	0.40	0.04	48.66	49.4	49.03	49.69	49.20	0.447	0.200	33.838	0.000413
17	0.52	0.40	0.07	51.78	52.96	52.28	50.42	51.86	1.075	1.155	34.292	0.000372
18	0.52	0.40	0.10	54.93	55.61	55.78	54.57	55.22	0.569	0.324	34.841	0.000328
19	0.59	0.30	0.04	36.48	35.31	36.63	36.83	36.31	0.684	0.467	31.198	0.000759
20	0.59	0.30	0.07	40.38	41.02	40.98	41.18	40.89	0.351	0.123	32.232	0.000598
21	0.59	0.30	0.10	47.89	48.68	47.08	48.57	48.06	0.738	0.545	33.632	0.000433
22	0.59	0.35	0.04	38.79	37.09	37.02	38.23	37.78	0.871	0.759	31.541	0.000702
23	0.59	0.35	0.07	40.40	39.66	40.74	41.34	40.54	0.701	0.491	32.154	0.000609
24	0.59	0.35	0.10	47.06	46.95	46.37	46.29	46.67	0.394	0.155	33.380	0.000459
25	0.59	0.40	0.04	36.65	37.46	37.12	36.00	36.81	0.633	0.400	31.316	0.000739
26	0.59	0.40	0.07	40.93	39.71	40.84	40.48	40.49	0.555	0.308	32.145	0.000610
27	0.59	0.40	0.10	46.15	45.84	46.45	45.70	46.04	0.335	0.112	33.261	0.000472

Step 5

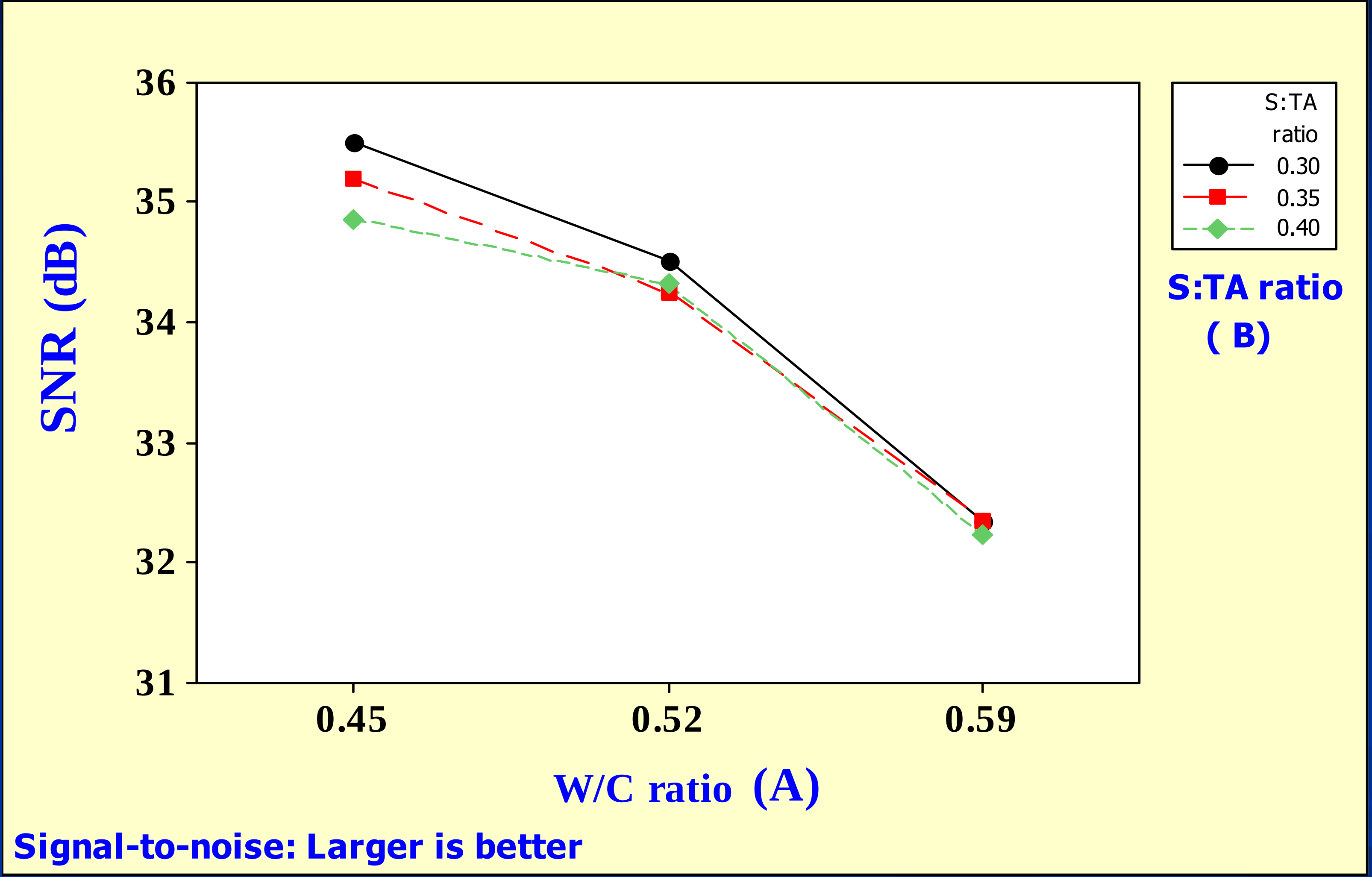
Analysis Results, Discussion and Determining of Optimum Design Parameters

Analytical Tools of DOE

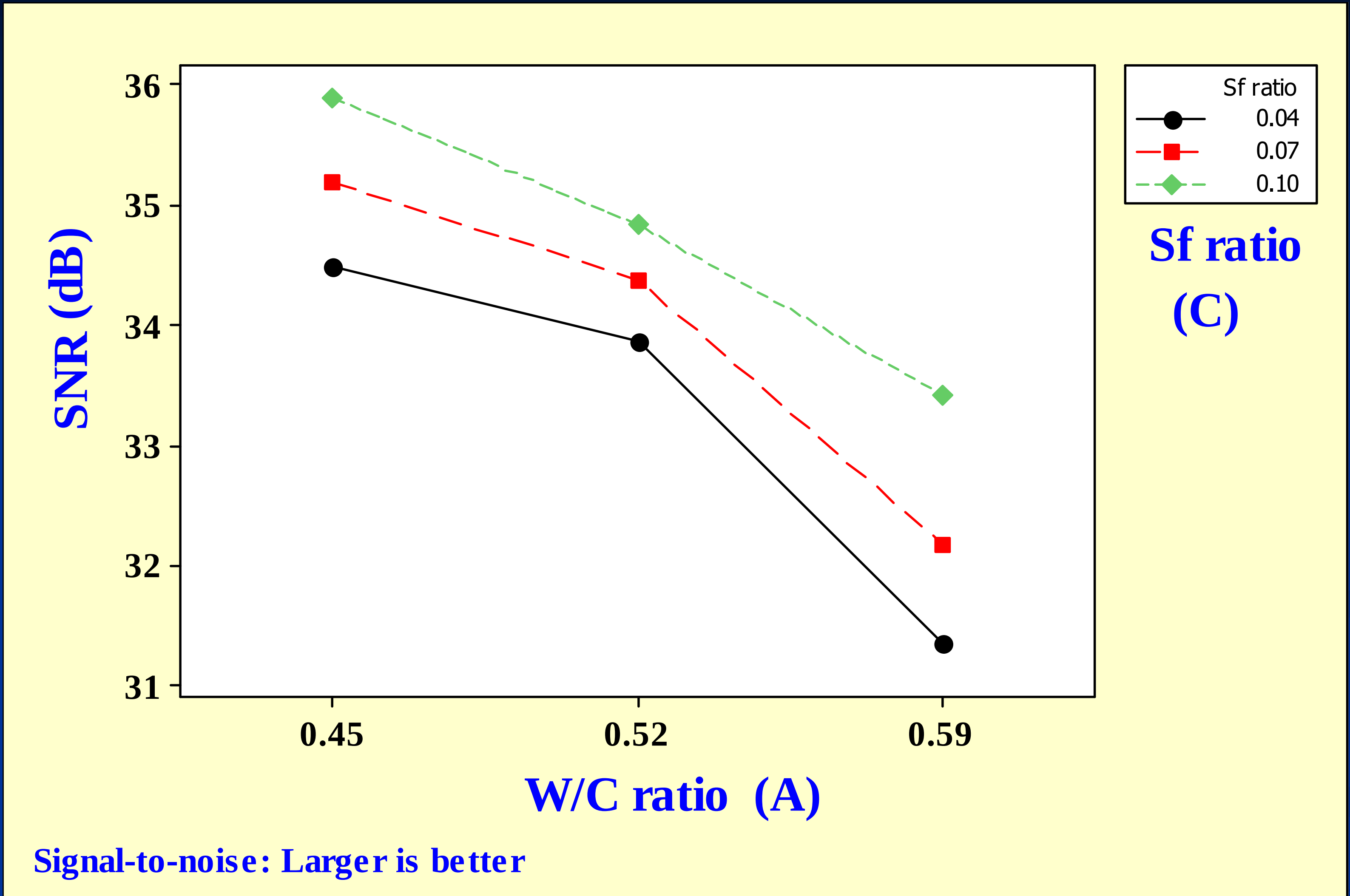
1. Main effects plot



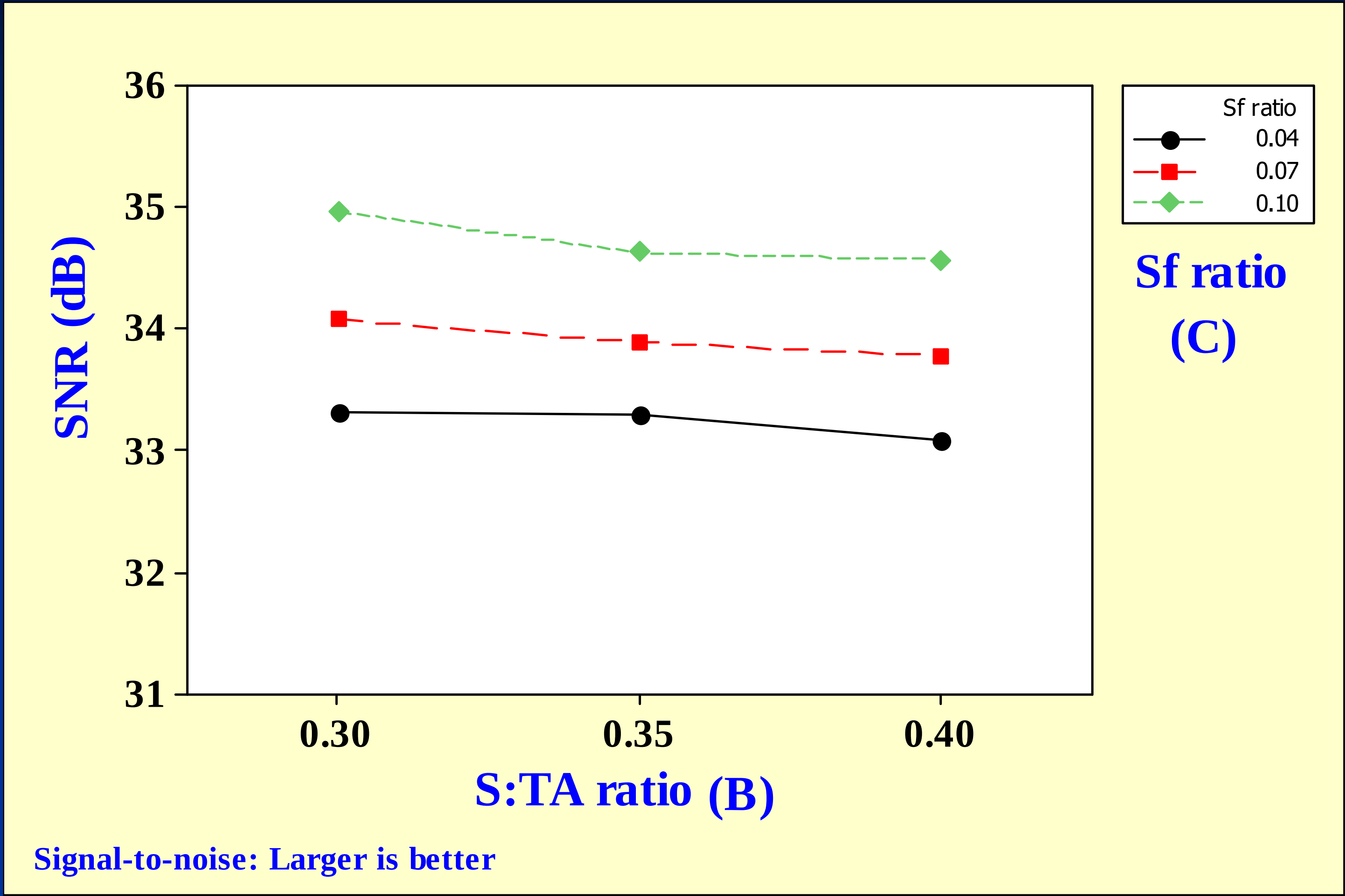
2. Interactions Plot



The Interaction Plot Between (W/C) ratio and (S:TA) ratio

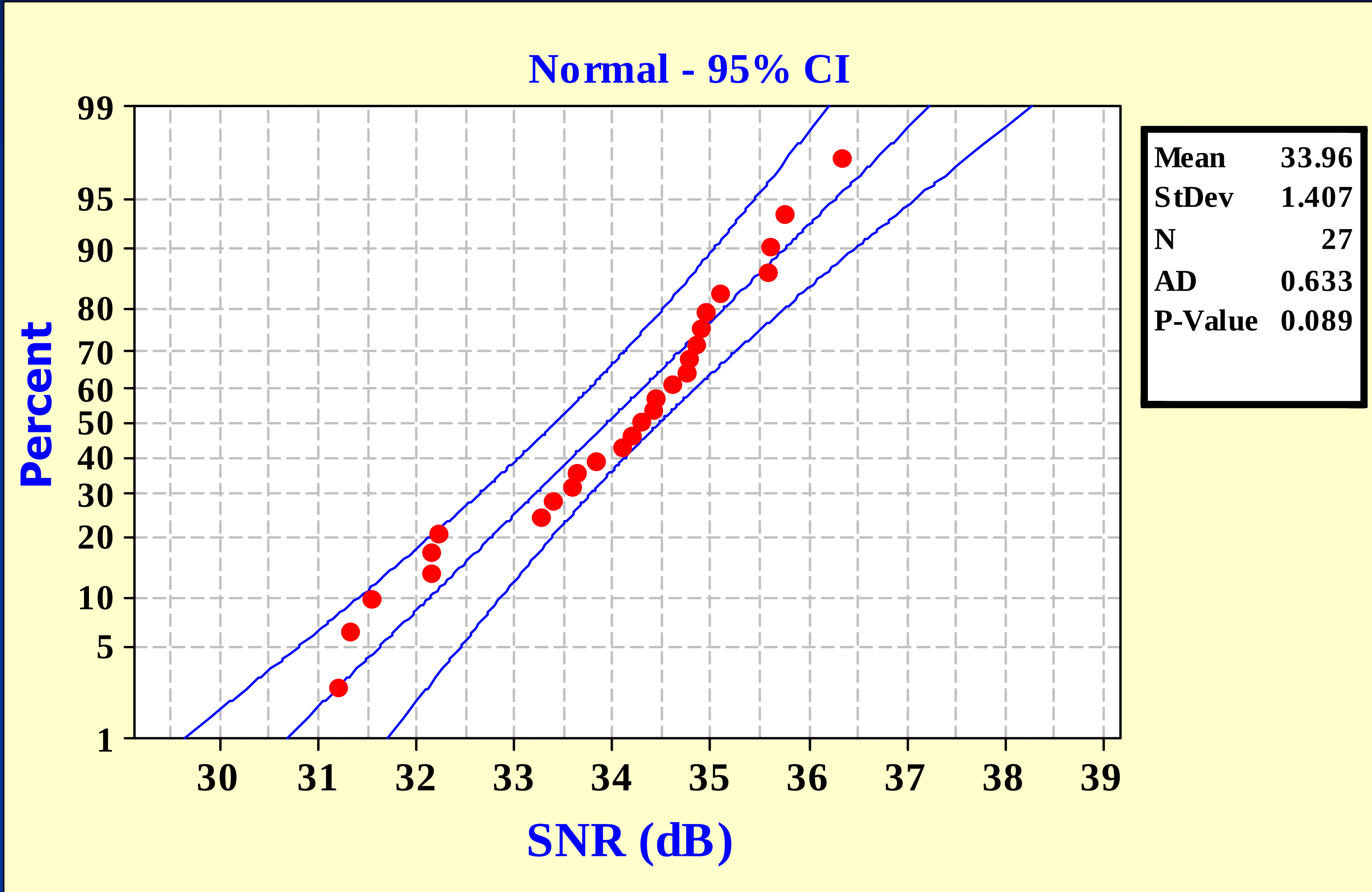


The Interaction Plot Between (W/C) ratio and (Sf) ratio



The Interaction Plot Between (S:TA) ratio and (Sf) ratio

3. Probability plot



The Probability Plot of the Signal to Noise Ratio

5. Response Table for SNR

Response table can indicate which factor has the largest impact on the response and which level of the factor is related to higher or lower response characteristic values.

Response Table for SNR

Levels	W/C	S:TA	Sf
1	35.19	34.12	33.23
2	34.36	33.94	33.92
3	32.32	33.81	34.72
Delta	2.87	0.31	1.49
Rank	1	3	2

Determination of Optimal Design Parameters of Concrete Mixtures Design

It is clear from the previous analysis the run number three (3) has the maximum SNR ratio which represents the minimum quality loss. The best combination is achieved when the mean of response (Compressive Strength = 65.55 MPa), SNR=36.330 dB, Loss function = $ 0.000233 and the levels are set at :

Run No. (3)	Factors	W/C ratio	S:TA ratio	Sf ratio
	Levels	0.45	0.30	0.10

Step 6 : Predicted Values of Optimum Performance

The predicted values can be used to determine which factor settings lead to the best result for your product or process.

❖ By Using Data From the Response Tables

The Predicted Response = $(A_1 + B_1 + C_3) - 2 \times T$

The Predicted SNR = (35.19 + 34.12 + 34.72) – 2 × 33.957 = 36.116

P SNR = 36.116 dB

The Predicted Mean = (57.66 + 51.58 + 54.86) - 2× 50.50 = 63.10

P Mean = 63.10 MPa

Step 7 : Confirmation Run

Results of Confirmation Runs

Trial No.	W/C Ratio (A_1)	S :TA Ratio (B_1)	Sf Ratio (C_3)	Response (Compressive Strength) (MPa)				Mean (MPa)	SNR (dB)
				R_1	R_2	R_3	R_4		
1	0.45	0.30	0.10	67.20	66.90	65.60	67.07	66.69	36.48
2	0.45	0.30	0.10	63.90	65.50	66.80	66.07	65.57	36.33
3	0.45	0.30	0.10	64.94	64.85	65.71	66.50	65.50	36.32
4	0.45	0.30	0.10	66.90	67.01	65.81	66.20	66.48	36.45

Conclusions

1. The best combination to achieve optimum compressive strength were obtained when, W/C ratio = 0.45 (A1), S:TA ratio = 0.30 (B1), and Sf ratio = 0.10 (C3).

2. In the main effects plot for S/N ratio, the greatest effect on signal to noise ratio are the factors W/C ratio and Sf ratio respectively however, S:TA ratio has very small effect.

Conclusions

3. **The results of the confirmation runs were very close to the predicted values. Therefore, the confirmation runs indicated that the selection of the optimal levels for all parameters is the best and predictions are reliable.**

Recommendations

1. In this study, W/C ratio, S:TA ratio and Sf ratio were selected as controllable factors to obtain better quality of compressive strength in concrete mixtures design, For similar work it is recommended that these factors can be used to investigate other quality characteristics such as impermeability, density.....etc).

2. Further research should be carried out to examine the effect of other factors such as (curing duration, compaction and vibration time, other types of admixtures ...etc) on the compressive strength.

3. These results were obtained in a laboratory facility, therefore, more research needs to be done in the outside of construction field.

Thanks For Your Attention