Concrete Strength

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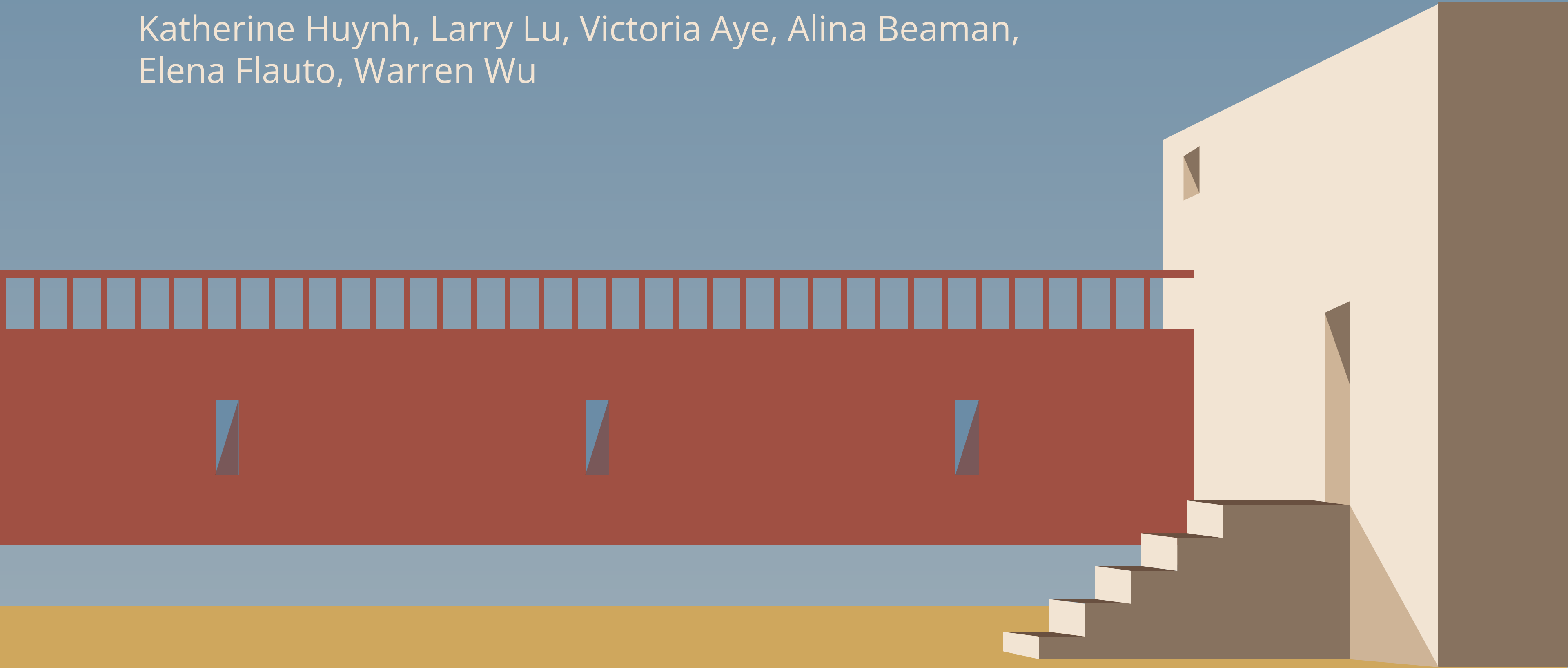
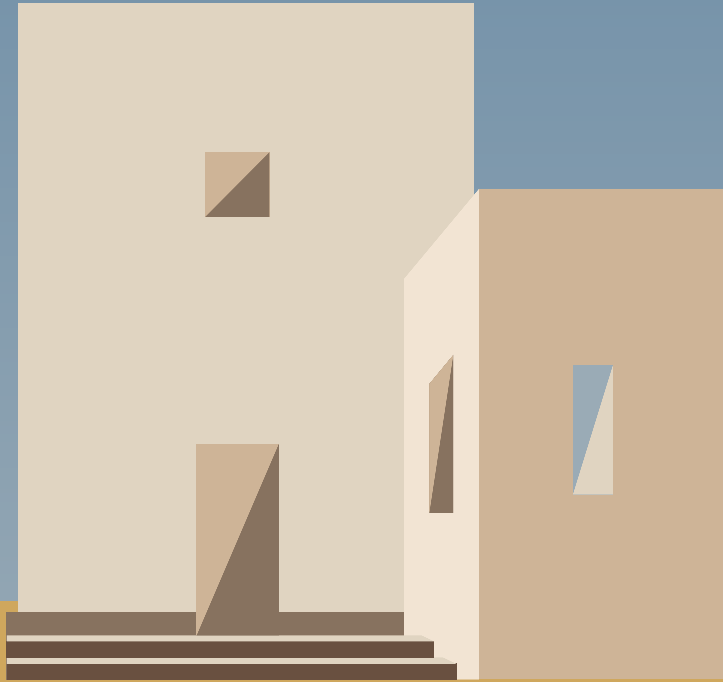


Project Goal

Predict the strength of concrete using a variety of predictors.



Data Set

1030 observations

Response Variable

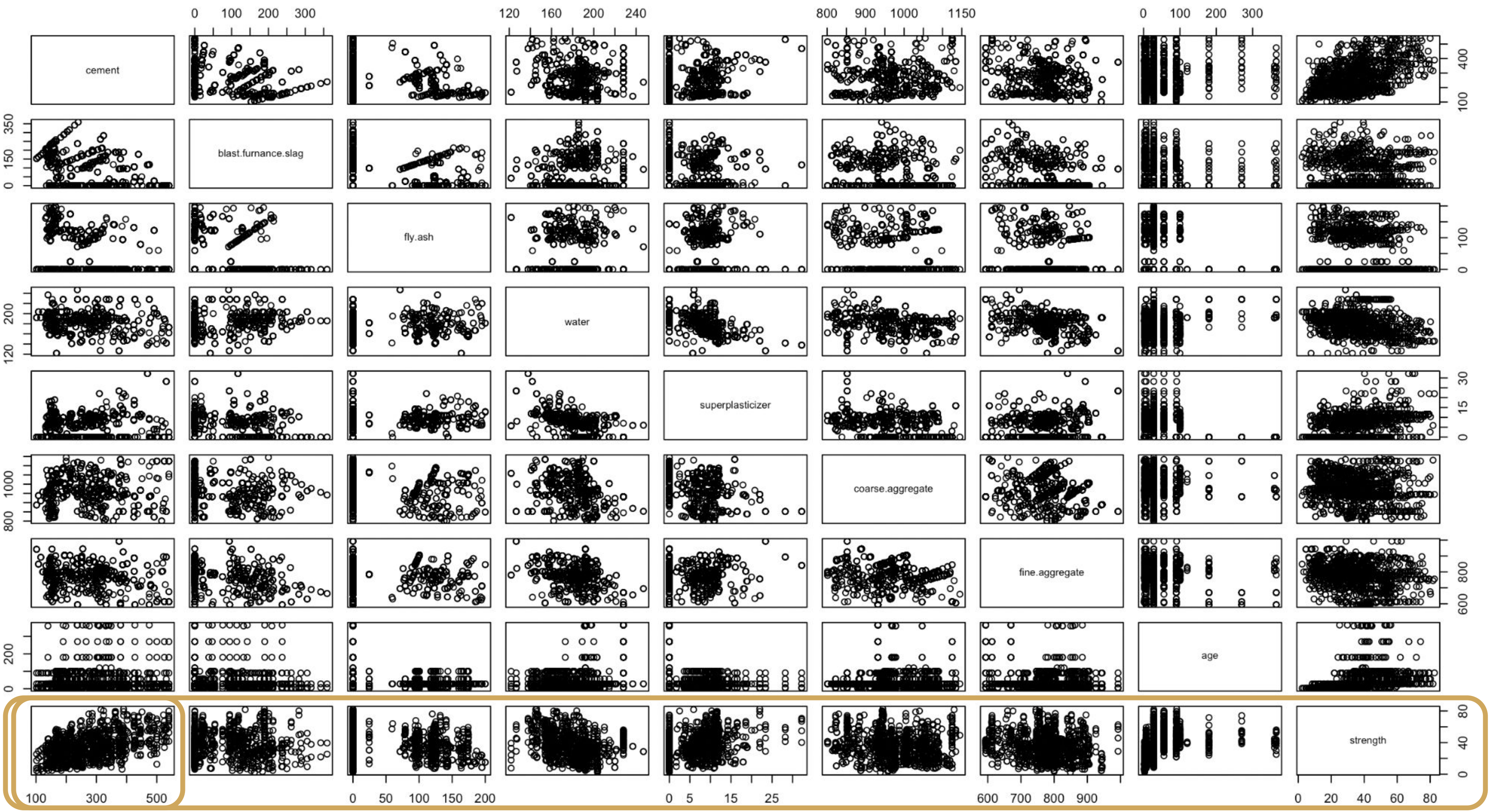
Concrete Compressive Strength (MPa - Pressure)

8 Predictor Variables (Density)

1. Cement (kg/m^3)
2. Blast Furnace Slag (kg/m^3)
3. Fly Ash (kg/m^3)
4. Water (kg/m^3)
5. Superplasticizer (kg/m^3)
6. Coarse Aggregate (kg/m^3)
7. Fine Aggregate (kg/m^3)
8. Age (day)

01

CLEANING & FULL MODEL



cement
blast.furnance.slag
fly.ash
water
superplasticizer
coarse.aggregate
fine.aggregate
age
strength

CLEANING
THE DATASET

Replace instances where Blast Furnace Slag, Fly Ash, or Superplasticizer = 0 with 1e-100

FULL MODEL SUMMARY

Call:
lm(formula = Strength ~ Cement + Blast.Furnace.Slag + Fly.Ash + Water + Superplasticizer + Fine.Aggregate + Coarse.Aggregate + Age, data = concrete)

R^2 = 0.6125

F - statistic: 204.3

P-value of anova = < 2.2e-16

Residuals:

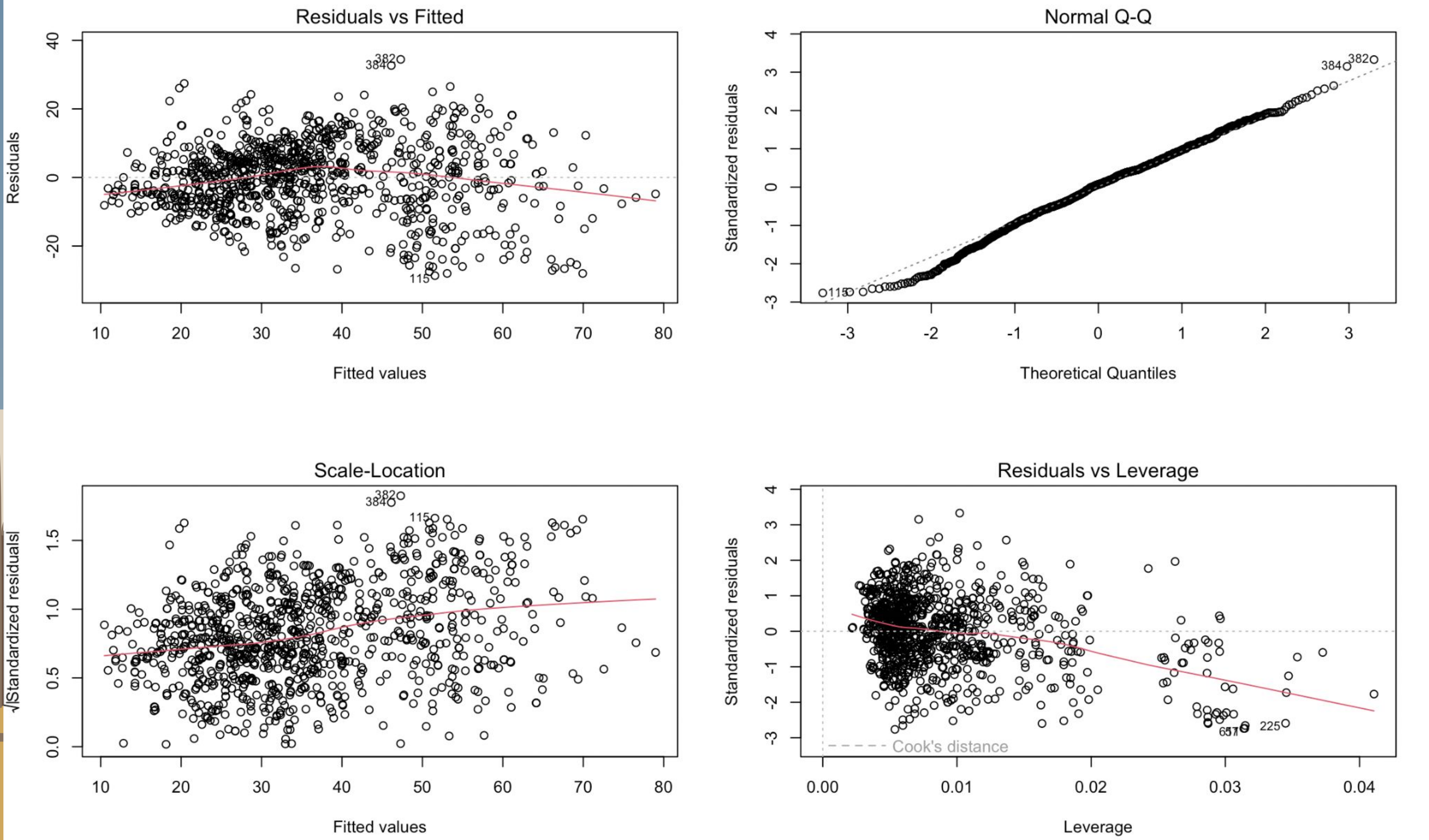
Min	1Q	Median	3Q	Max
-28.654	-6.302	0.703	6.569	34.450

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-23.331214	26.585504	-0.878	0.380372
Cement	0.119804	0.008489	14.113	< 2e-16 ***
Blast.Furnace.Slag	0.103866	0.010136	10.247	< 2e-16 ***
Fly.Ash	0.087934	0.012583	6.988	5.02e-12 ***
Water	-0.149918	0.040177	-3.731	0.000201 ***
Superplasticizer	0.292225	0.093424	3.128	0.001810 **
Fine.Aggregate	0.020190	0.010702	1.887	0.059491 .
Coarse.Aggregate	0.018086	0.009392	1.926	0.054425 .
Age	0.114222	0.005427	21.046	< 2e-16 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 10.4 on 1021 degrees of freedom
Multiple R-squared: 0.6155, Adjusted R-squared: 0.6125
F-statistic: 204.3 on 8 and 1021 DF, p-value: < 2.2e-16

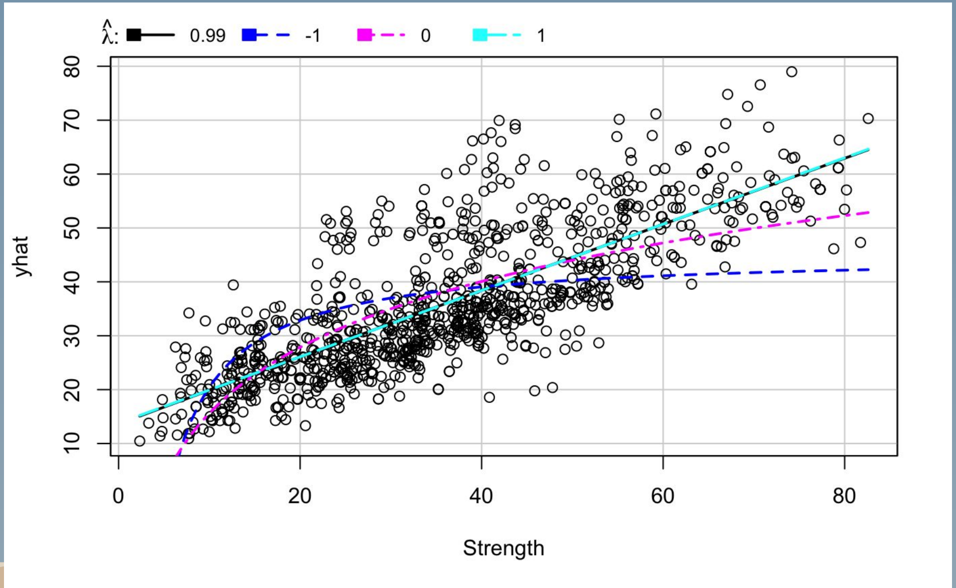


Residuals vs Fitted
Residuals
Fitted values
382
384
115
Normal Q-Q
Standardized residuals
Theoretical Quantiles
384
382
115
Scale-Location
√|Standardized residuals|
Fitted values
382
384
115
Residuals vs Leverage
Standardized residuals
Leverage
Cook's distance
225

|02

TRANSFORMED MODEL

INVERSE RESPONSE PLOT SUMMARY



inverseResponsePlot Output

lambda	RSS
<dbl>	<dbl>
0.9911575	67960.75
-1.0000000	119174.38
0.0000000	79501.38
1.0000000	67961.49

POWER TRANSFORM SUMMARY

powerTransform Output

bcPower Transformations to Multinormality

	Est Power	Rounded Pwr	Wald Lwr Bnd	Wald Upr Bnd
Y1	0.5460	**0.50**	0.4773	0.6147
Y2	0.4257	**0.50**	0.2943	0.5571
Y3	0.0023	**0.00**	0.0014	0.0032
Y4	-0.0025	**0.00**	-0.0034	-0.0016
Y5	0.9917	**1.00**	0.6940	1.2894
Y6	0.0072	**0.01**	0.0062	0.0082
Y7	1.1501	**1.00**	0.5571	1.7431
Y8	1.8035	**2.00**	1.3873	2.2197
Y9	-0.0313	**0.00**	-0.0673	0.0048

Suggested Transformations

Y1 (Strength) → take square root
Y2 (Cement) → take square root
Y3 (Blast Furnace Slag) → take log
Y4 (Fly Ash) → take log
Y5 (Water) → none
Y6 (Superplasticizer) → take log
Y7 (Coarse Aggregate) → none
Y8 (Fine Aggregate) → square
Y9 (Age) → take log

TRANSFORMED MODEL

$$
\begin{aligned}
\sqrt{(\text{Strength})} = \beta_0 & \\
& + \beta_1 * \sqrt{(\text{Cement})} \\
& + \beta_2 * \log(\text{Blast Furnace Slag}) \\
& - \beta_3 * \log(\text{Fly Ash}) \\
& + \beta_4 * \log(\text{Superplasticizer}) \\
& - \beta_5 * (\text{Water}) \\
& - \beta_6 * (\text{Coarse Aggregate}) \\
& - \beta_7 * (\text{Fine Aggregate})^2 \\
& + \beta_8 * \log(\text{Age}) \\
& + \varepsilon
\end{aligned}
$$

TRANSFORMED MODEL SUMMARY

```
Call:
lm(formula = I(Strength^0.5) ~ I(Cement^0.5) + log(Blast.Furnace.Slag) + log(Fly.Ash) + Water + log(Superplasticizer) + Coarse.Aggregate
+  (I(Fine.Aggregate^2)) + log(Age), data = concrete)

Residuals:
    Min      1Q  Median      3Q     Max
-2.2762 -0.3687  0.0305  0.3828  1.7664

Coefficients:
                          Estimate    Std. Error    t value    Pr(>|t|)
(Intercept)               6.264e+00   7.902e-01     7.928      5.82e-15 ***
I(Cement^0.5)             2.185e-01   8.734e-03     25.013     < 2e-16 ***
log(Blast.Furnace.Slag)   2.543e-03   2.391e-04     10.638     < 2e-16 ***
log(Fly.Ash)              -5.226e-04  2.642e-04     -1.978     0.0482 *
Water                     -2.128e-02  1.627e-03     -13.078    < 2e-16 ***
log(Superplasticizer)     2.608e-03   3.088e-04      8.443     < 2e-16 ***
Coarse.Aggregate          -1.149e-03  3.862e-04     -2.975     0.0030 **
I(Fine.Aggregate^2)       -1.764e-06  2.533e-07     -6.963     5.95e-12 ***
log(Age)                  7.598e-01   1.643e-02      46.257    < 2e-16 ***
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.617 on 1021 degrees of freedom
Multiple R-squared:   0.82,    Adjusted R-squared:  0.8186
F-statistic: 581.5 on 8 and 1021 DF,  p-value: < 2.2e-16
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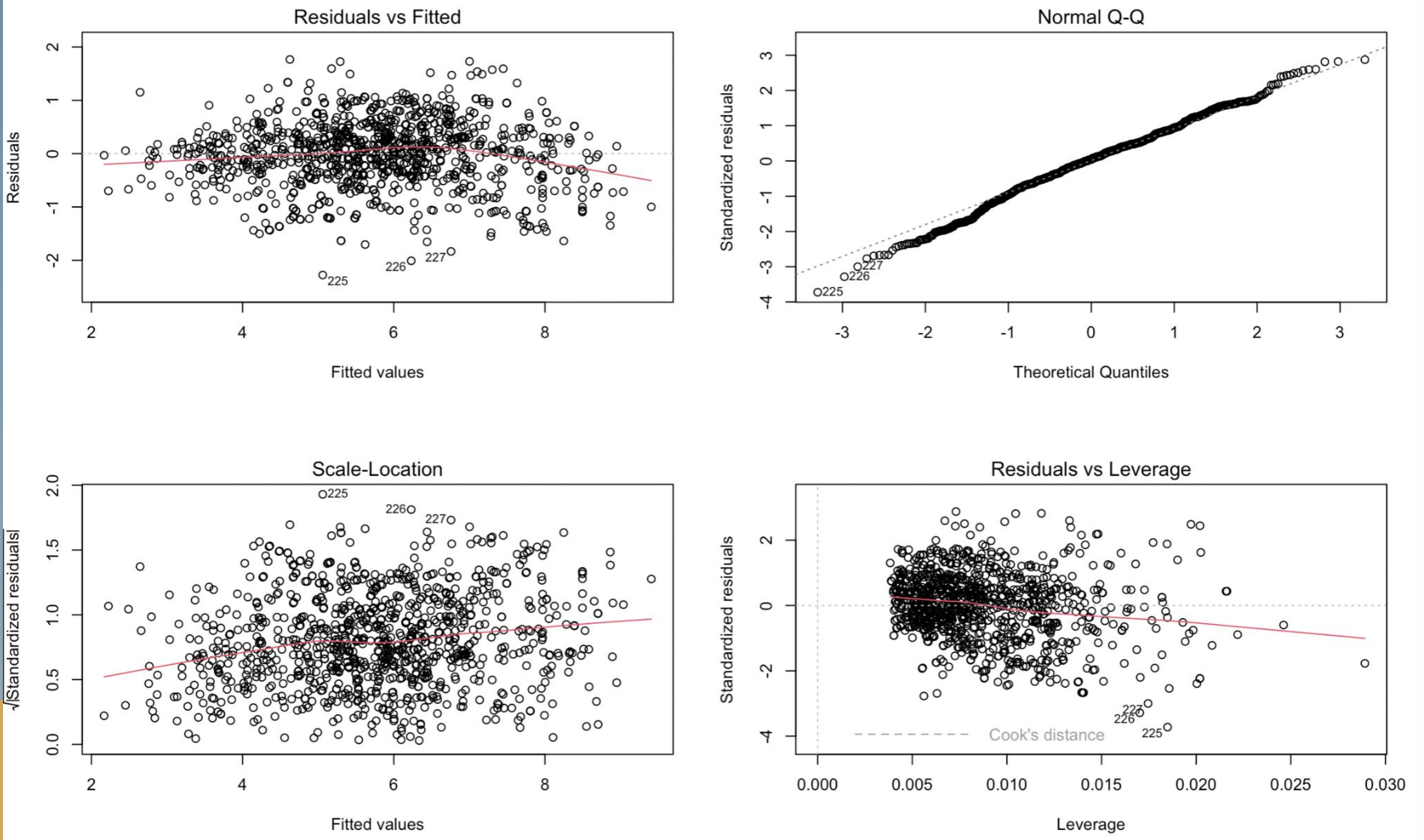
R^2 = 0.8186

F - statistic: 581.5

P-value of anova = < 2.2e-16



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Residuals
Fitted values
225
226
227
Normal Q-Q
Standardized residuals
Theoretical Quantiles
Scale-Location
√|Standardized residuals|
Residuals vs Leverage
Leverage
Cook's distance

FINAL REGRESSION MODEL

$$
\begin{aligned}
\sqrt{\text{(Strength)}} = \;& 6.264 \text{ (Intercept)} + \\
& + 0.2185 * \sqrt{\text{(Cement)}} \\
& + 0.002543 * \log\text{(Blast Furnace Slag)} \\
& - 0.0005226 * \log\text{(Fly Ash)} \\
& + 0.002608 * \log\text{(Superplasticizer)} \\
& - 0.02128 * \text{(Water)} \\
& - 0.001149 * \text{(Coarse Aggregate)} \\
& - 0.000001764 * \text{(Fine Aggregate)}^2 \\
& + 0.7598 * \log\text{(Age)} \\
& + \varepsilon
\end{aligned}
$$

03

INTERPRETATION & DISCUSSION

INTERPRETATION OF MODEL IN CONTEXT

Intercept	When all predictor variables = 0, square root of strength is estimated to be 6.264 MPa.
Cement	An increase of 1 kg in square root of cement leads to a 0.2185 MPa average **increase** in square root of strength.
Blast Furnace Slag	An increase of 1 in log of blast furnace slag leads to a 0.002534 MPa average **increase** in square root of strength.
Fly Ash	An increase of 1 in log of fly ash leads to a 0.0005226 MPa average **decrease** in square root of strength.
Water	An increase in 1 kg of water leads to a 0.02128 MPa average **decrease** in square root of strength.
Superplasticizer	An increase of 1 kg of log of superplasticizer leads to a 0.002608 MPa average **increase** in square root of strength.
Coarse Aggregate	An increase in 1 kg of coarse aggregate leads to a 0.001149 MPa average **decrease** in square root of strength.
Fine Aggregate	An increase in 1kg of fine aggregate squared leads to a 0.000001764 MPa average **decrease** in square root of strength.
Age	An increase in 1 in log of age leads to a 0.7598 MPa average **increase** in square root of strength.

THANK YOU!

SOURCES

- Yeh,I-Cheng. (2007). Concrete Compressive Strength. UCI Machine Learning Repository. https://doi.org/10.24432/C5PK67.