Effects of moisture variation on concrete mixes and methods to control final mix quality

Introduction

- Concrete raw materials:
  - Aggregate
  - Cement
  - Water
- The problems:
  - Quality
    - Yield
    - Consistence/Workability
  - Strength
    - Cement

Introduction

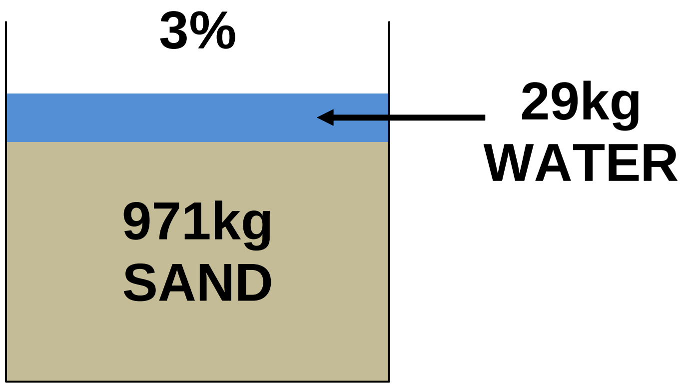
- The solution
  - Moisture Control
    - In Aggregates
    - In Mixers

- The cost savings:
  - Time
  - Waste
  - Raw Material

Material weighing

- Concrete plants usually batch raw materials by weight
  - When weighing aggregates this includes the weight of the water

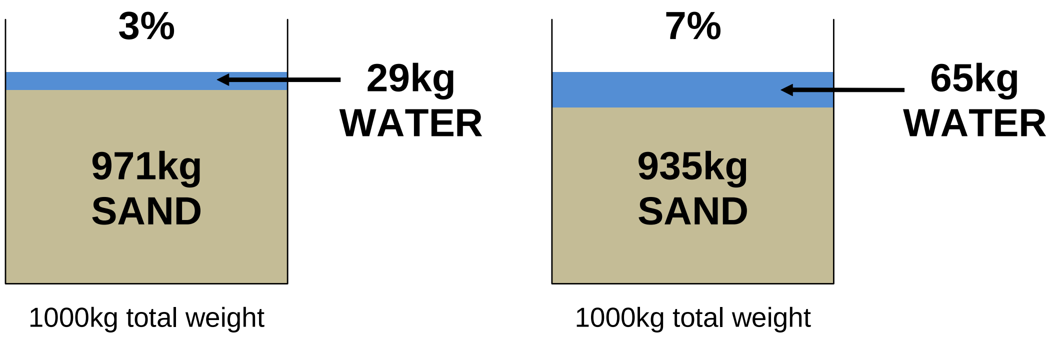
- 1,000kg Sand at 3% moisture
  - 971kg Dry Sand
  - 29kg Water



1000kg total weight

Quality Problems - Proportioning

- An example containing sand and cement
- Weighing
  - 1000kg Sand
  - 160kg Cement
- 1,000kg Sand at 3% moisture
  - 971kg Sand
  - 160kg Cement
  - A/C Ratio = 6.1
- 1,000kg Sand at 7% moisture
  - 935kg Sand
  - 160kg Cement
  - A/C Ratio = 5.8

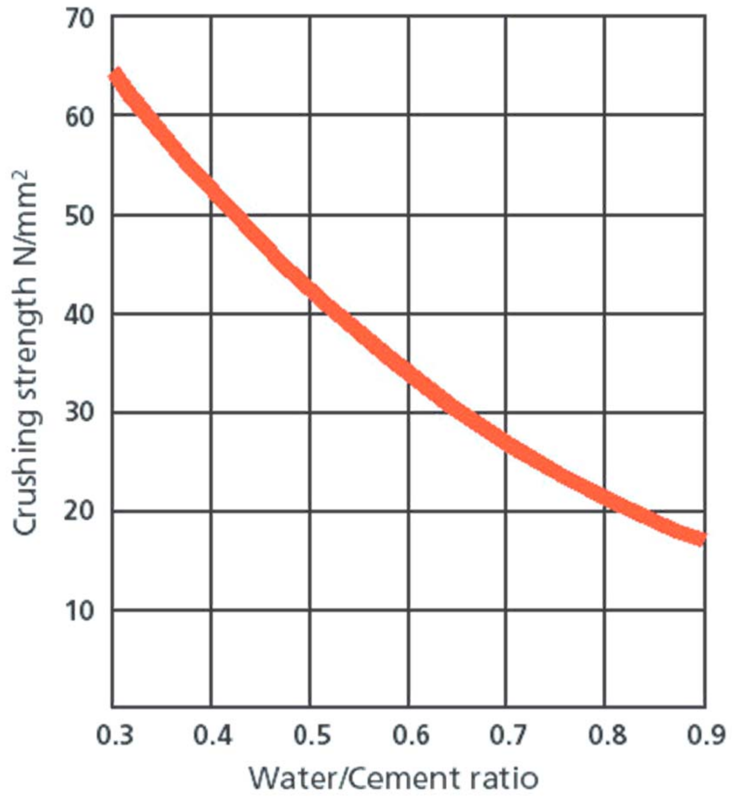


Quality Problems - Consistence

- Affected by aggregate proportioning (Aggregate/Cement Ratio)
- Also known as “Workability”
  - Mould and Form pouring issues
  - Curing problems
  - Water addition by end user
- Colour density
  - Cost of colour pigments
  - Affected by surface area of sand/aggregates as different proportions of each is weighed

Quality Problems - Strength

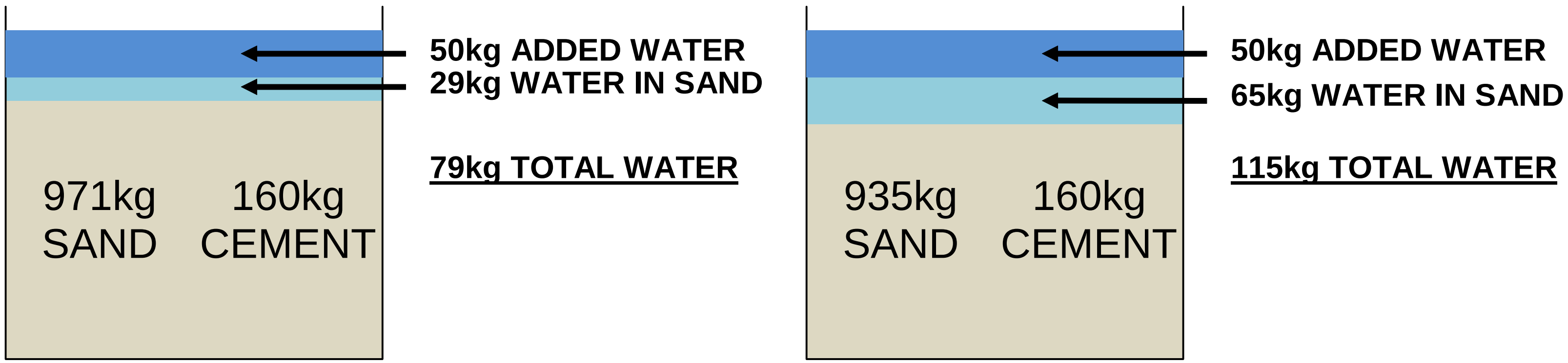
- Concrete strength
  - Direct relationship with Water/Cement Ratio



Quality Problems - Strength

- Example:
  - 2 simple mixes of sand and cement with the same water added

Sand @ 3% **Sand @ 7%**



w/c = 79 ÷ 160

w/c = 0.5

w/c = 115 ÷ 160

w/c = 0.72

Effect of Moisture on Strength

- Example concrete mix
  - Cement = 350kg/m³
  - Sand and aggregate = 1,900kg/m³
  - Water added in mixer = 175kg/m³
  - Target Water/Cement ratio = 0.5
- Variation of 1.0% in aggregates (after any correction for moisture)
  - Water in aggregates = 1900 * 0.01 = 19kg
  - Actual water in mix = 175 + 19 = 194kg
  - Cement needed = 194 / 0.5 = 388kg
- So to achieve the mix design an **extra 38kg** of cement is needed

Effect of Moisture on Strength

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- Example concrete mix
  - Cement = 350kg/m³
  - Sand and aggregate = 1,900kg/m³
  - Water added in mixer = 175kg/m³
  - Target Water/Cement ratio = 0.5
- Variation of 0.2% in aggregates (after any correction for moisture)
  - Water in aggregates = 1900 * 0.002 = 3.8kg
  - Actual water in mix = 175 + 3.8 = 178.8kg
  - Cement needed = 178.8 / 0.5 = 358kg
- So to achieve the mix design only 8kg of cement is needed
- So **30kg of cement is saved** per m³

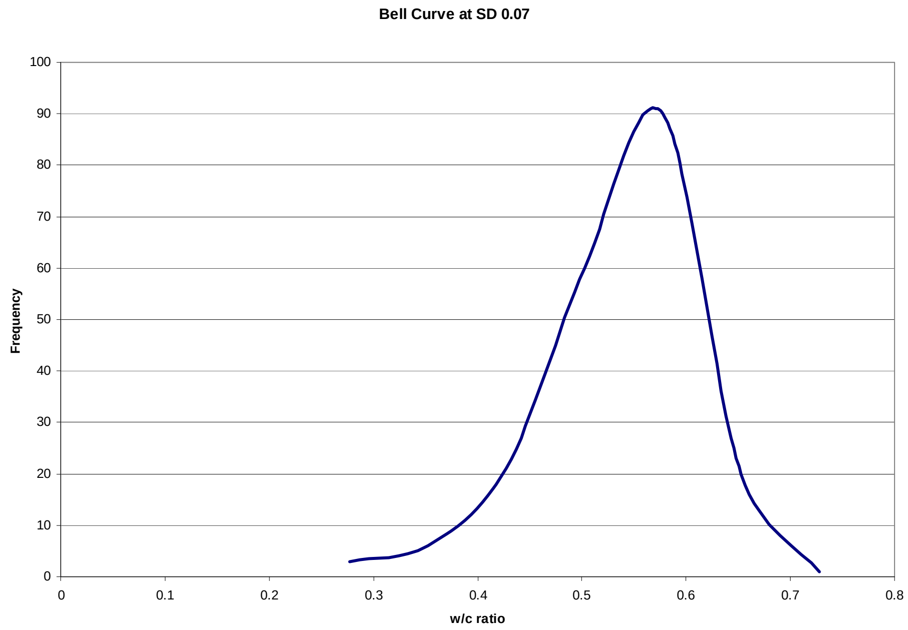
Concrete Strength - Overdesign

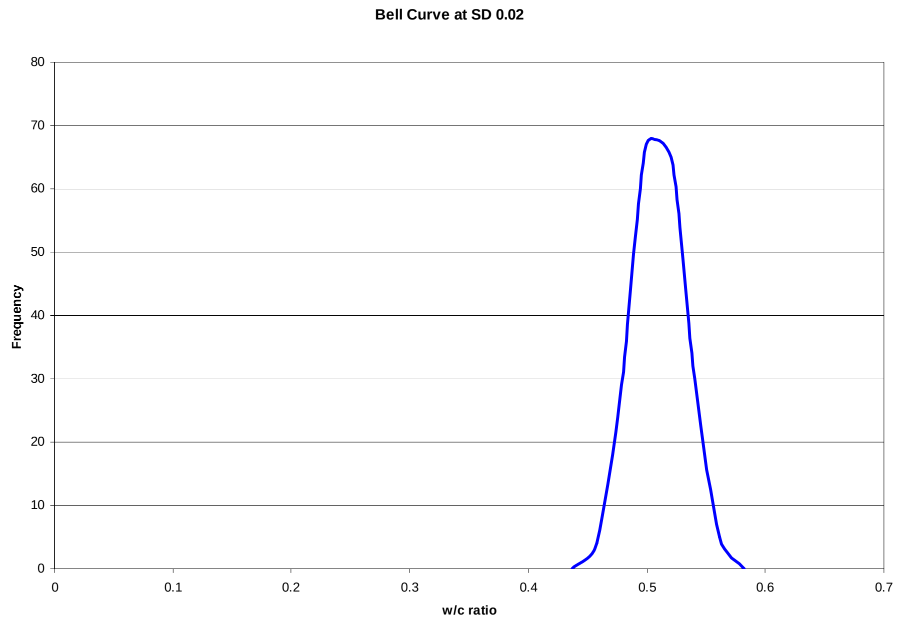
- Overdesign allows a producer to guarantee a target strength
  - Water/Cement ratios designed to allow for moisture change in aggregates
  - Effect is making stronger concrete than needed
    - i.e. For C30 a mix is designed for a C40 average strength
  - European standards require overdesign based on twice the Standard Deviation
    - Standard Deviation indicates the spread of strengths around an average

- Adding Moisture Control
  - Reduces the variation of batches due to moisture
  - Reduces the Standard Deviation for strength
  - Allows the cement in the mix design to be reduced

Concrete Strength Variation

- Plant without moisture control
- Plant with moisture control



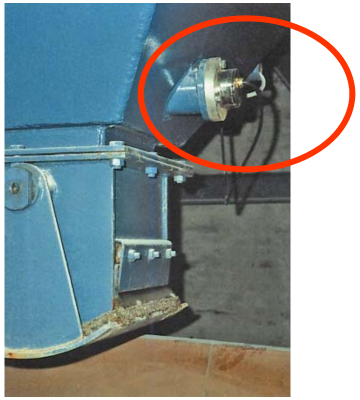


Effect of Moisture on Yield

- Example concrete mix
  - Cement = 350kg/m^3
  - Sand and aggregate = 1,900kg/m^3
  - So total dry materials should be 1900 + 350 = 2250kg/m^3
- If the moisture in aggregates of 5%
  - Dry aggregates = 1900 / 1.05 = 1810kg
  - So total dry materials is now 1810 + 350 = 2160kg
- So the dry weight yield is 2160 / 2250 = 0.96m^3
  - Inefficient use of the cement

Controlling the water

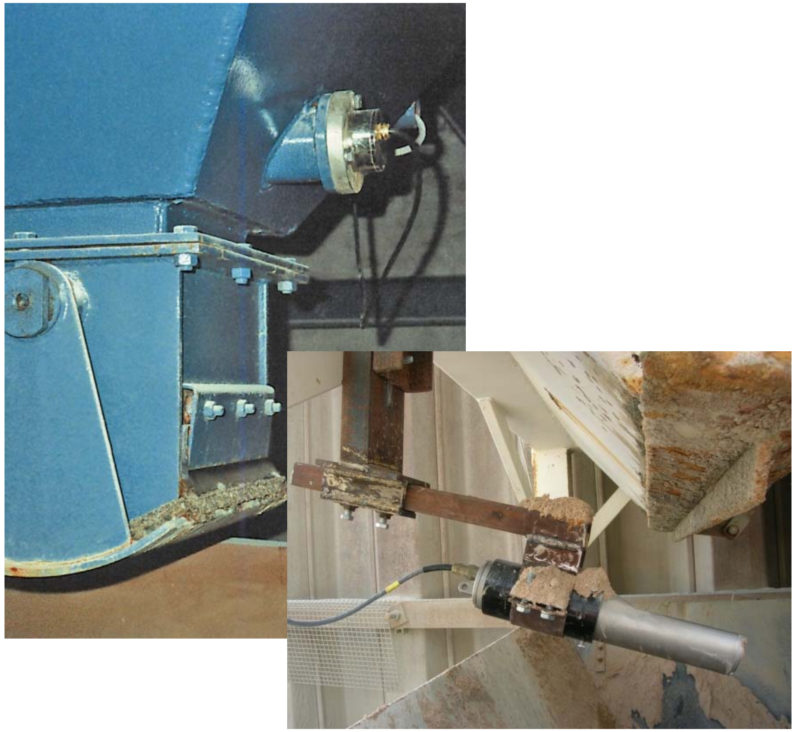
- In the aggregate bins
  - Weigh the aggregate and stop at 75%
  - Calculate the final target
  - Finish weighing the aggregate



- In the mixer
  - Load materials
  - Measure in the dry mix
  - Add water to reach a target moisture value
  - Wet mix

Aggregate Control

- Moisture measurement equipment
  - Measurement in aggregate bins or on conveyor belts

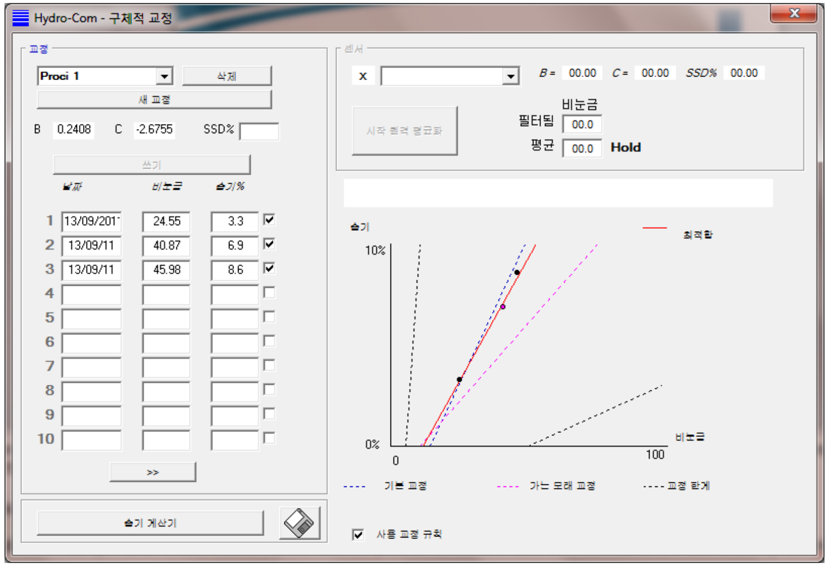


Aggregate Control

- Calibration
  - Simple calibration process
    - Sample material being measured whilst recording sensor value
    - Test sample in laboratory
    - Moisture given by formula:

$$M = \frac{W_{wet} - W_{dry}}{W_{dry}}$$

M = Moisture
W_{wet} = Weight of sample when wet
W_{dry} = Weight of sample after drying to "bone dry"



  - Good quality equipment needs no recalibration
  - Check calibration every 1-3 months

Aggregate Control

- Control Example
  - Weigh 75% of target weight
  - Calculate average moisture of material
  - Recalculate target weight

$$T_{new} = T_{old} + \frac{T_{old} \cdot M}{100}$$

M = Moisture
T_{new} = Target weight adjusted for moisture content
T_{old} = Original target weight

  - Dose remaining weight

Aggregate Control

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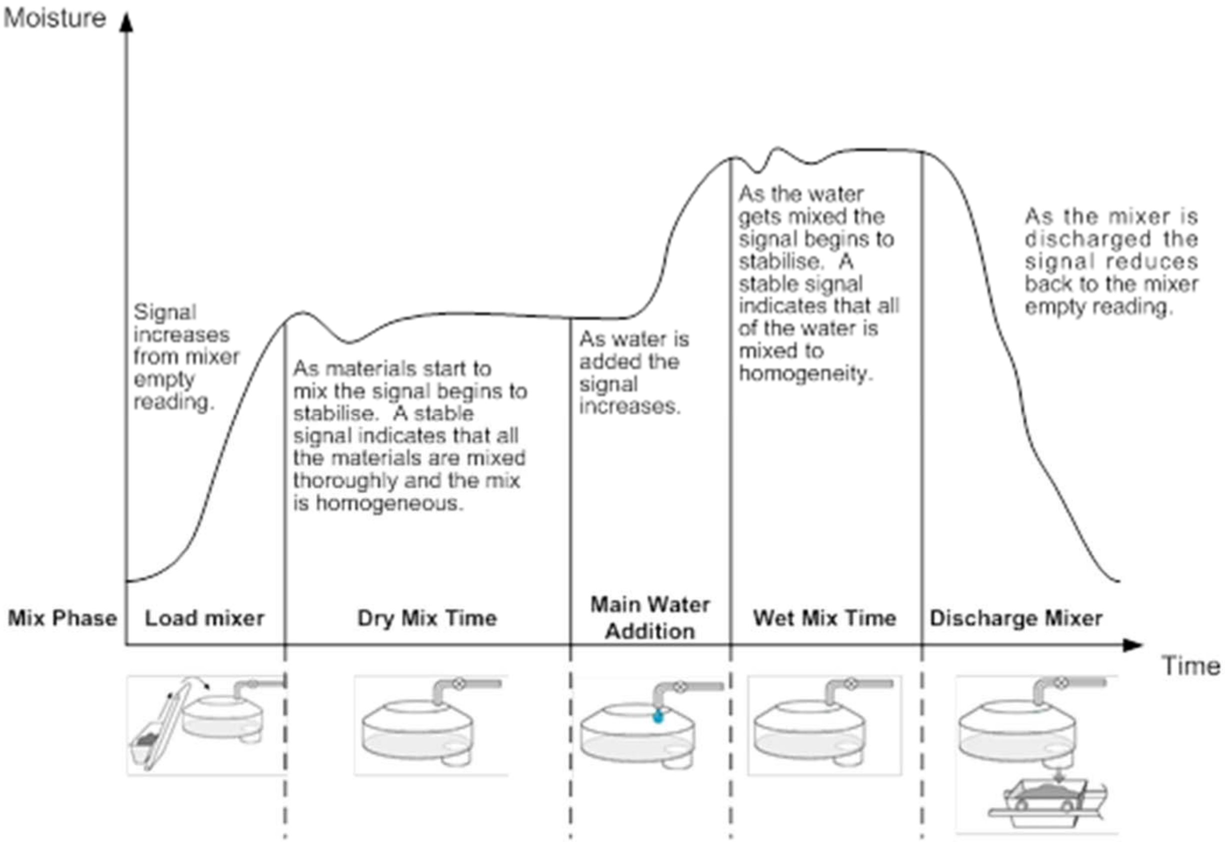
- Control Example
  - Example weighing 1000kg
    - Step 1: Weigh 75% (750kg)
    - Step 2: Read average moisture from sensor (5%)
    - Step 3: Recalculate target
      - New Target = 1000 + (1000 * 5/100) = 1050kg
    - Step 4: Dose remaining material (1050 – 750 = 300kg)

Mixer Control

- Control Example
  - Example mix cycle



Mixer Control

- Measurement equipment
  - Sensor in mixer floor (Hydro-Mix) or on scraper arm (Hydro-Probe Orbiter)
  - Must be linear over the working range
- Calibration
  - Simple calibration technique
    - Run a test batch adding a preset quantity of water
      - Take an average moisture reading at the end of the dry mix
      - Record the water flow into the mixer
      - Take an average moisture reading at the end of the wet mix
    - Repeat with another test batch varying the quantity of water as required
    - Average moisture reading at the of the wet mix becomes the target

Mixer Control

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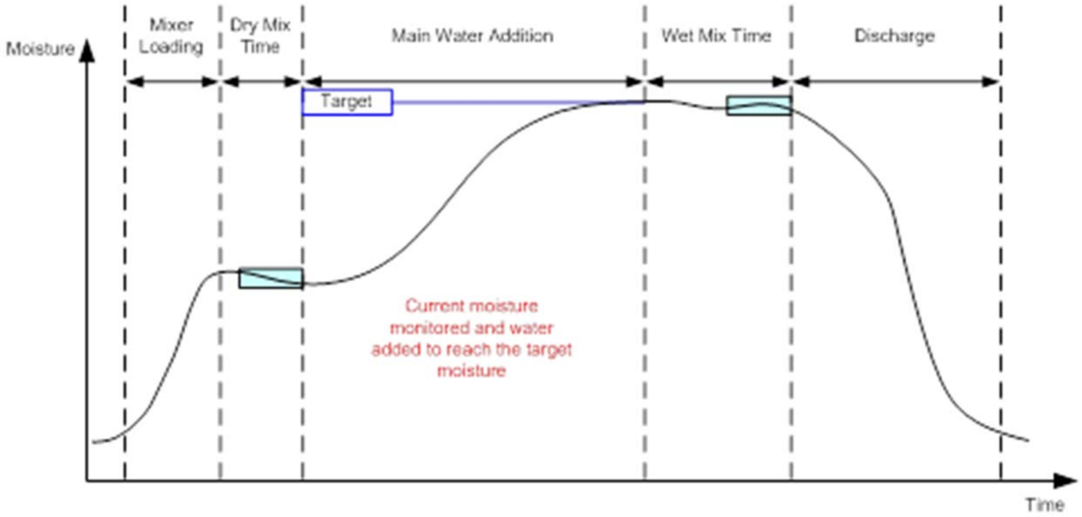
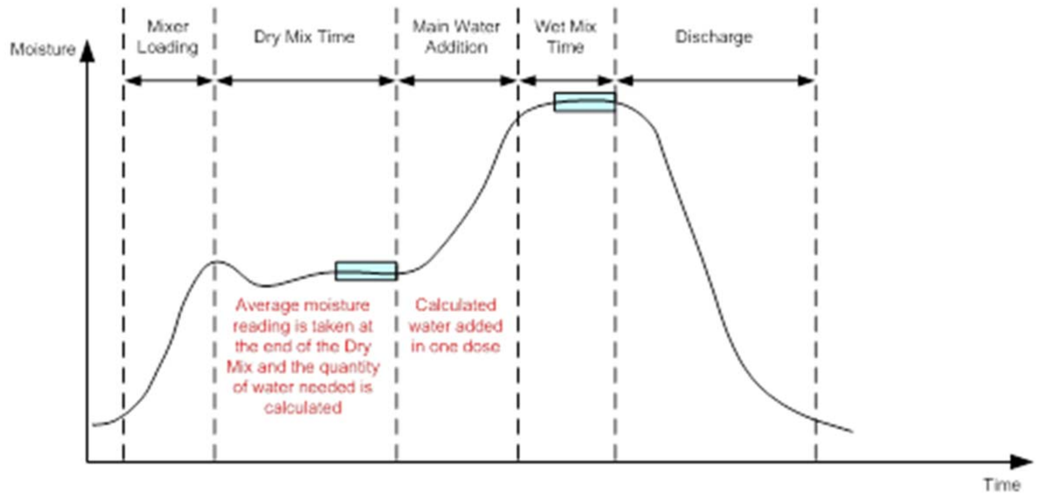
- Control techniques
  - PID based control
    - Use target from calibration
    - Use continuous sensor value for control



    - Vary flow rate of water into mixer as sensor value approaches target

Mixer Control

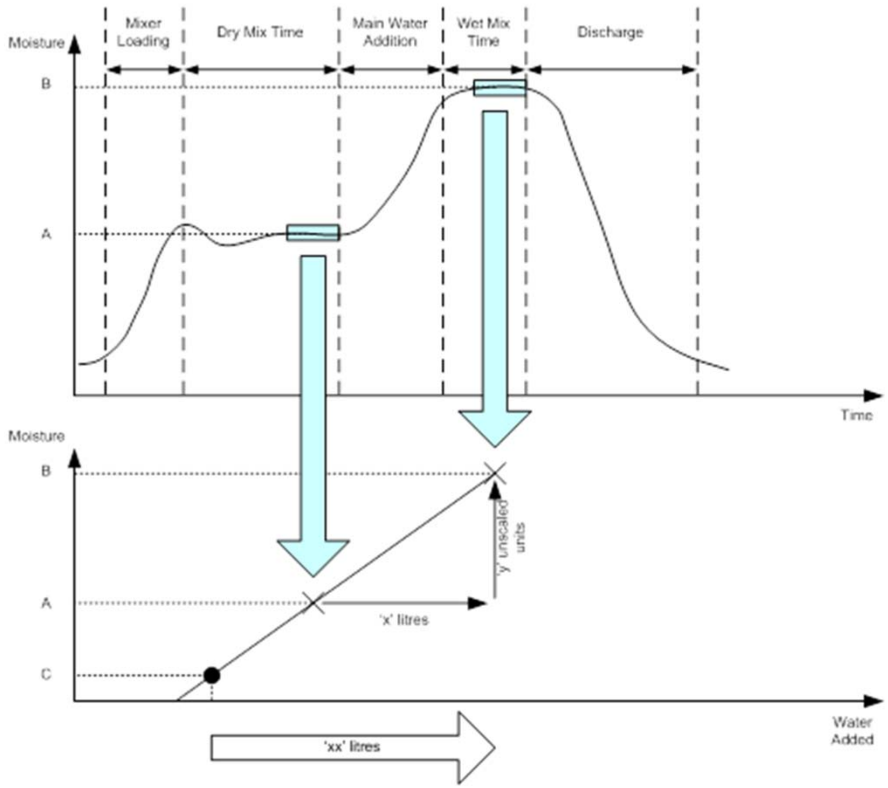
- Control techniques
  - Calculation based control
    - Use target from calibration
    - Use sensor value at end of dry mix for control



    - Calculate water to add after dry mix
    - Add water in “one shot”

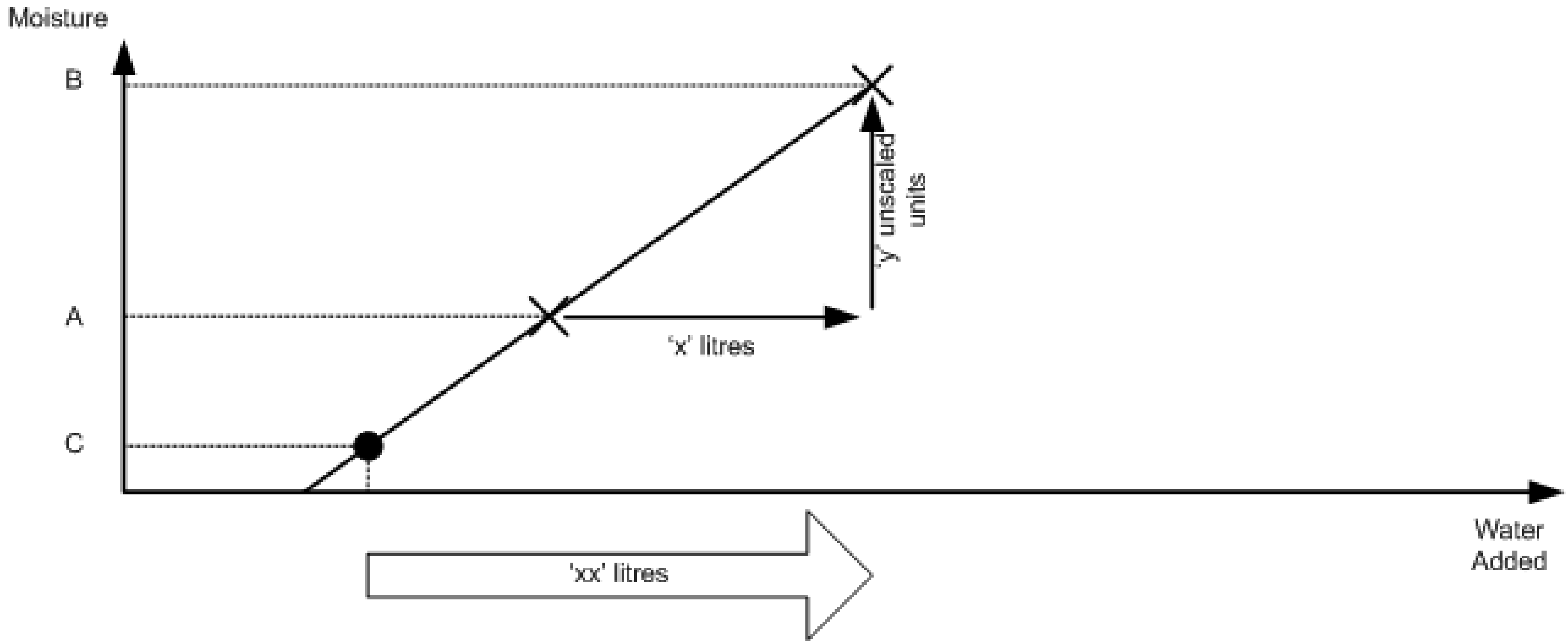
Mixer Control

- Control techniques
  - Calculation based control



Mixer Control

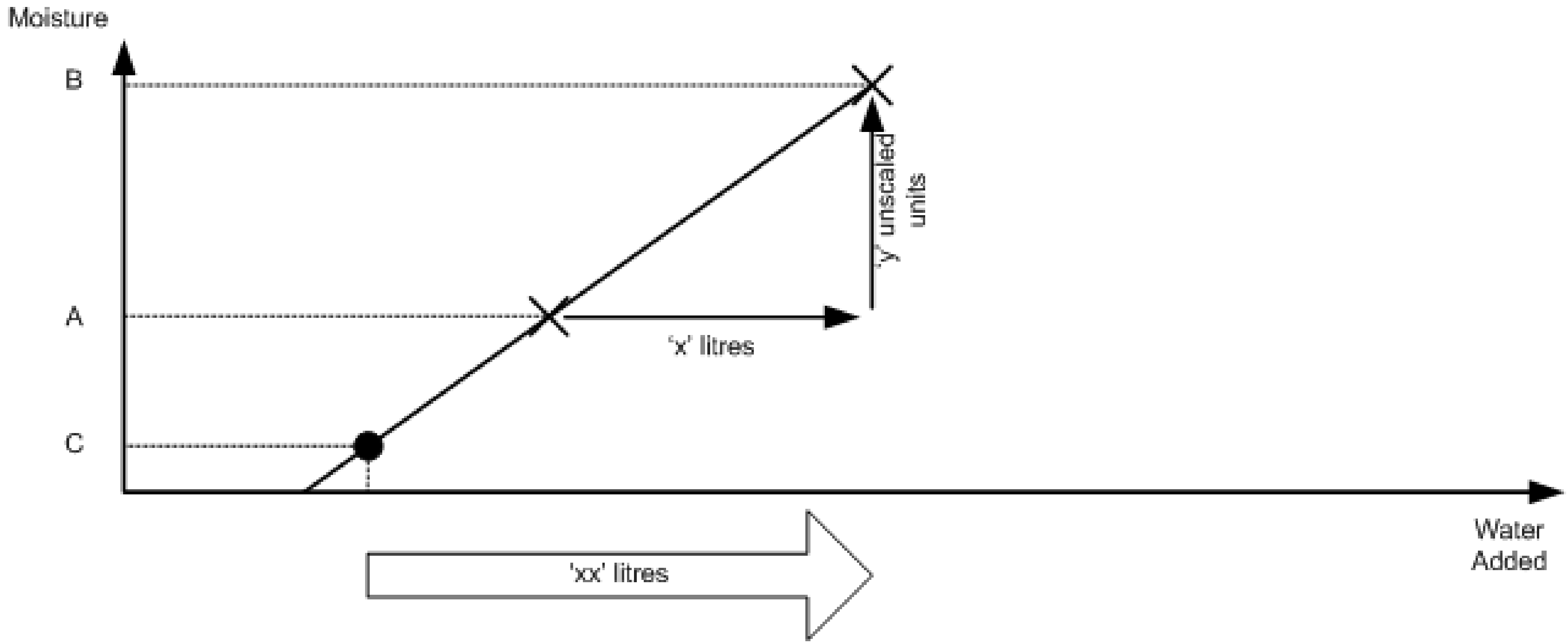
- Control techniques
  - Calculating calibration coefficients



$$M = \frac{V}{W_{Dry}} \qquad Grad = \frac{M}{US_{Wet} - US_{Dry}}$$

Mixer Control

- Control techniques
  - Calculating water addition



$$M = Grad \cdot (US_{Wet} - US_{Dry}) \qquad V = M \cdot W_{Dry}$$

Mixer Control

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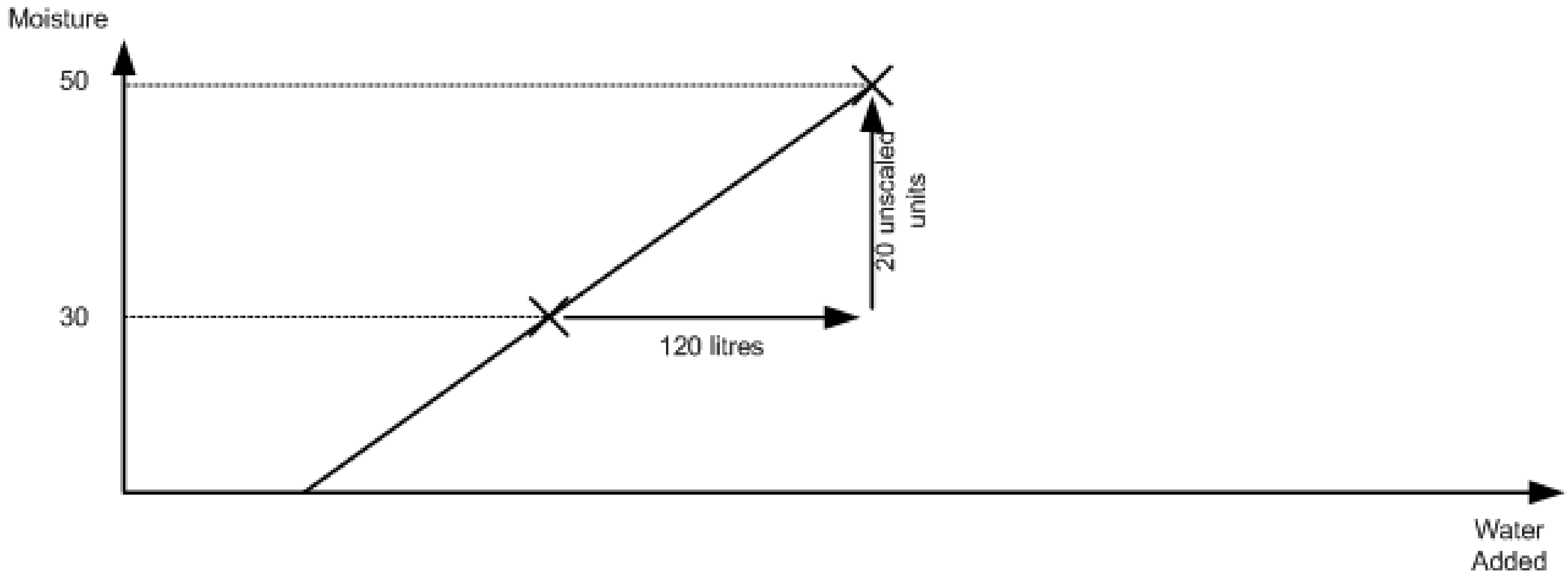
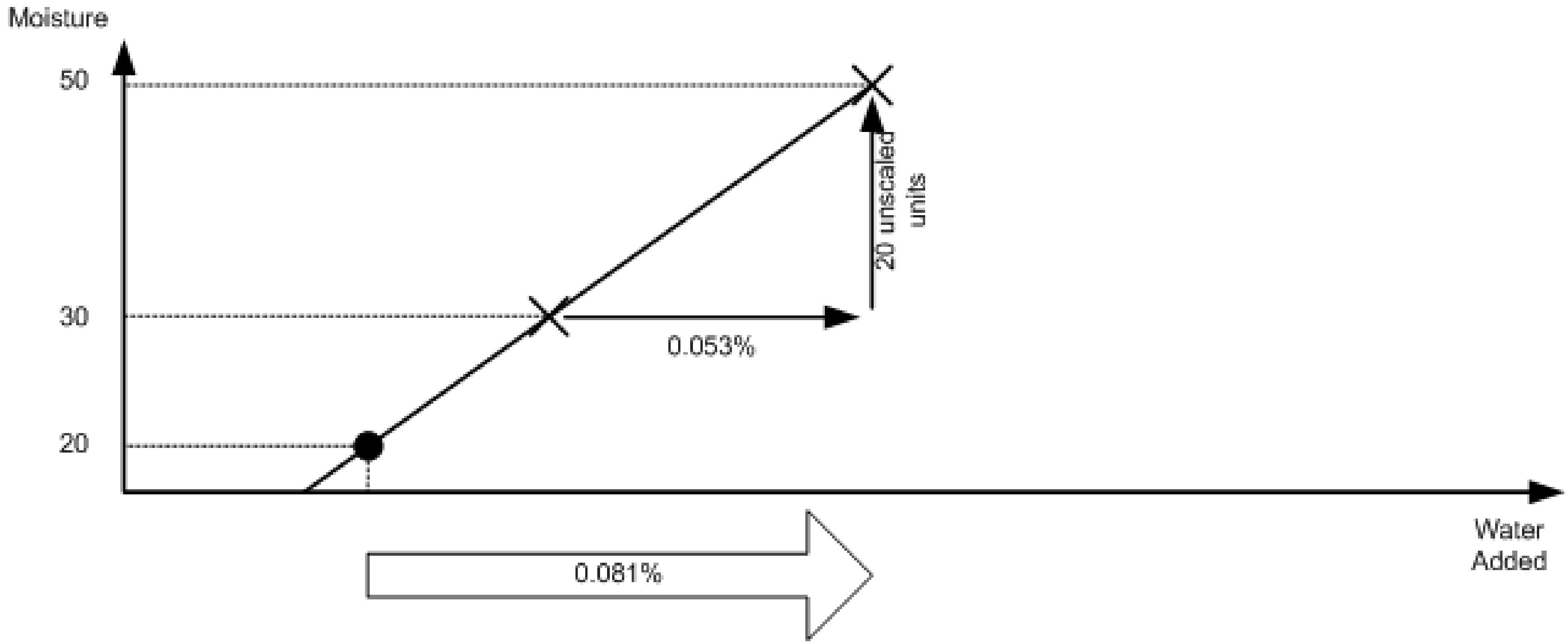
- Control example
  - Calculating calibration coefficients – 2250kg mix



$$M = \frac{120}{2250} = 0.0533 \qquad Grad = \frac{0.0533}{50 - 30} = 0.0027$$

Mixer Control

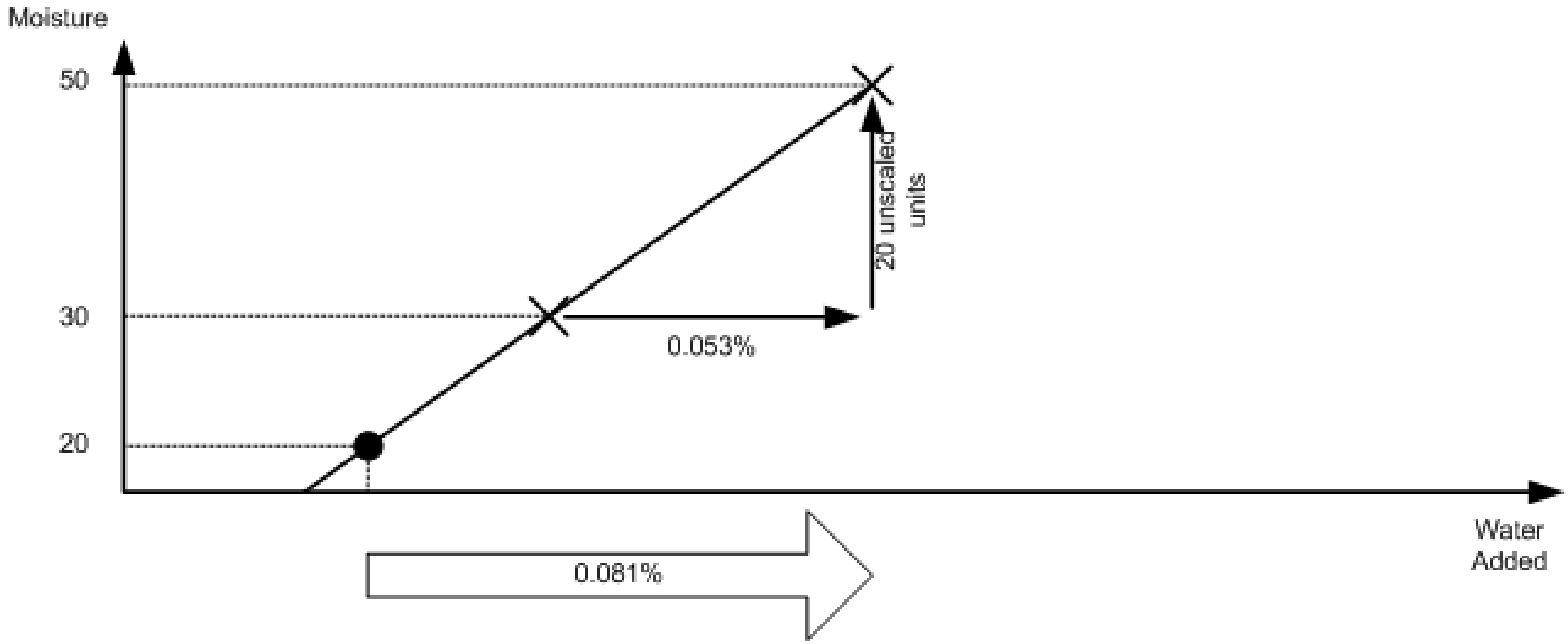
- Control example
  - Calculating water addition – 2250kg mix



$$M = 0.0027 \cdot (50 - 20) = 0.081 \qquad V = 0.081 \cdot 2250 = 180\ litres$$

Mixer Control

- Control example
  - Calculating water addition – 3000kg mix



$$M = 0.0027 \cdot (50 - 20) = 0.081 \qquad V = 0.081 \cdot 3000 = 243\ litres$$

The cost saving

- Quality
  - Correct quantities of admixtures and cement used
- Yield
  - Correct batch sizes are made reducing delivery errors
- Cement
  - 1000kg Cement costs ~ USD120,000

  - So saving 30kg/m³ = **USD 3.60 /m³**

Microwave Moisture Sensors

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- A cost effective moisture solution
  - Payback for a sensor and installation is less than 3 months (based on $50m^3$/day)
- What to look for in a microwave moisture sensor
  - Rugged/Reliable
    - Sensor is designed for use in aggregates/concrete
  - Accurate and easy to calibrate
    - Linear calibration will give an accuracy of 0.2%
    - Temperature stable calibration
  - Easy to integrate
    - 0-20mA, 4-20mA and 0-10v Analogue Outputs
  - Local presence for training, service and support
  - A proven brand

Hydronix

- Hydronix design, manufacture and sell microwave moisture measurement and control equipment
- Industry leader of digital sensors, controls and service
- First company to develop microwave technique in 1982
- Focus on sensor technology and service
- Over 50,000 installations world wide
- Continually investing in research
- Customer Focus – Your satisfaction, guaranteed!

Conclusions

- Control the moisture in the aggregates
- Control the water addition into the mixer
- Reduce the water/cement ratio variation
- Improve the yield
- Reduce the cement
- Reduce the cost

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Thank you