Modern concept and approach to control of quality of production of concrete

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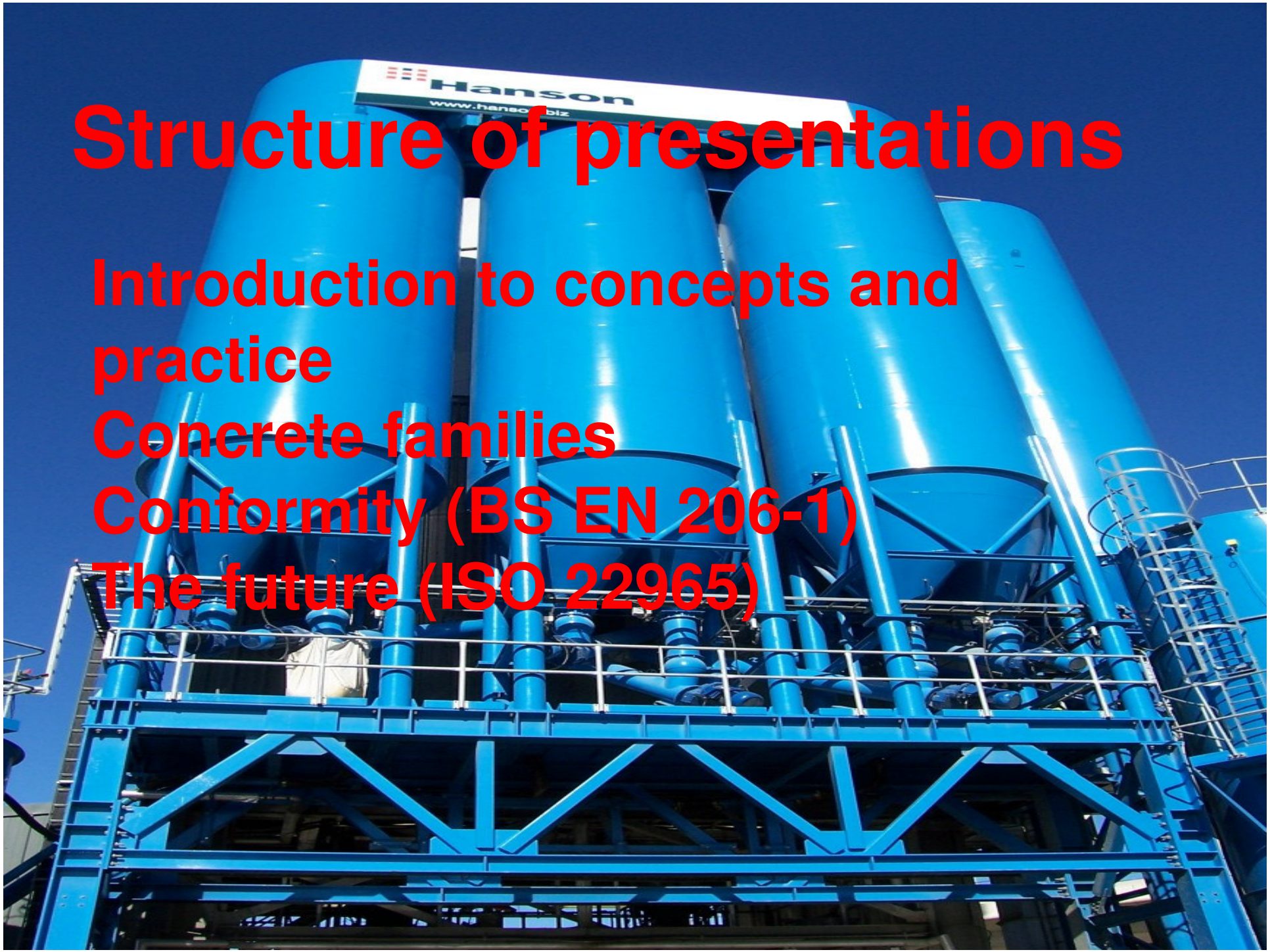


Structure of presentations

Introduction to concepts and practice
Concrete families
Conformity (BS EN 206-1)
The future (ISO 22965)


Introduction to concepts and practice
09.45 – 10.15

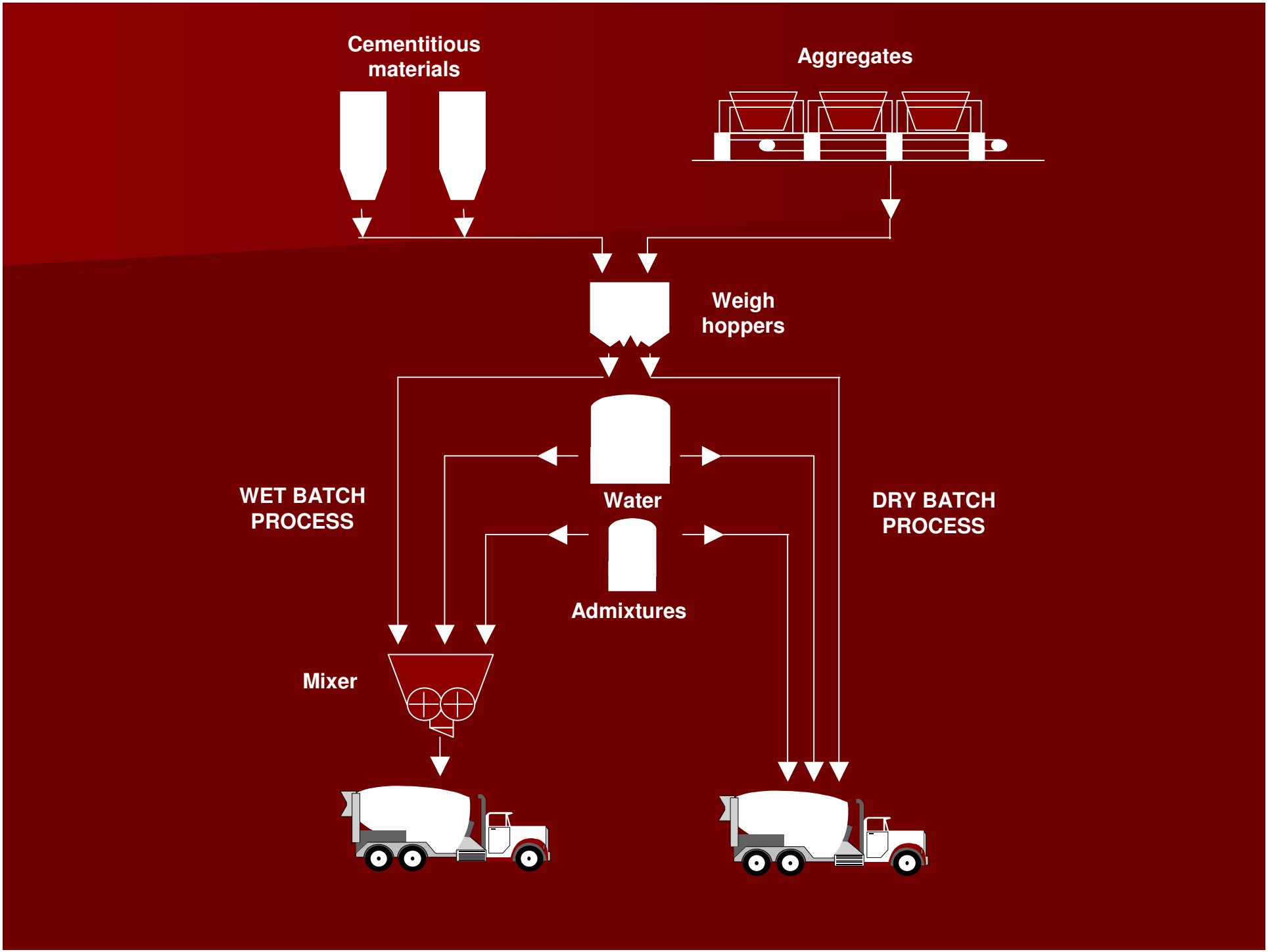
Terms

- Confusion over the terms ‘compliance’ and ‘conformity’
- People ‘comply with’ e.g. the contractor complies with the specification
- Things ‘conform to’ e.g. the cement conforms to BS EN 197-1
- The term ‘compliance’ wrongly used in older BSs, e.g. BS 5328

Terms

- **Conformity** – set of tests and evaluation undertaken by the **concrete producer** to show that the concrete supplied conformed to its specification
- **Identity test** – test(s) undertaken by the **specifier** to determine if a batch or series of batches of concrete came from a conforming population (acceptance test in all but name)

The production of concrete


Cementitious materials
Aggregates
Weigh hoppers
Water
Admixtures
WET BATCH PROCESS
DRY BATCH PROCESS
Mixer

Production control

- Production control comprises all measures necessary to maintain the properties of concrete in conformity to specified requirements

Production control

- It includes:
  - Selection of materials
  - Concrete mix proportioning
  - Concrete production
  - Inspection and tests
  - The use of the results of the tests on constituent materials, fresh and hardened concrete and equipment
  - (Conformity control)

The reality of production control

- A set of mix designs are established by testing and other means (computer mix design software) to give the relationship between mix proportions, consistence and strength for sets of the constituent materials available at the plant

The reality of production control

- When a specification is received, mix proportions are selected that:
  - Conform to limitations on constituent materials
  - Are expected to give the specified characteristic strength plus a margin ($\geq 1.64\sigma$)
  - Satisfy the maximum w/c ratio (target value should be at least 0.02 less than any specified maximum)
  - Satisfy the minimum cement content

The reality of production control

- For convenience, if the mix proportions are controlled by the maximum w/c ratio or minimum cement content, the producer will equate these to a target strength for production control purposes
- For production control purposes, prescribed concrete are also equated to a target strength

The reality of production control

- The ready-mixed plant is routinely maintained and checked
- In particular the accuracy of batching is checked
- In UK, batch weights of aggregates based on saturated surface dry condition


1
2
5


The reality of production control
When batching aggregates, account is taken of any surplus water

The reality of production control

- Different views on the benefits of moisture probes in the aggregate bins
- For ‘normal’ concrete, it is often adequate to simply add water until the target consistence is achieved
- Such an approach relies upon the accurate batching of the other constituents


ELBA
Baumaschinen
Construction Equipment
Speichern
Schaltpunkt
Power
20
40
60
80
100
Konsistenz % Consistency
ELBA
AD
CAPACITY

The reality of production control

- Manual plants are being progressively replaced by computer controlled plants with autographic recording equipment
- With many large companies, control is exercised centrally
- The risk of plant failures can be minimised but they cannot be eliminated entirely

The reality of production control

- When supplying concrete, the producer will batch the mix proportions that are expected to give the target strength
- When a concrete is tested there will be a scatter of results (usually normally distributed) due to batching and testing variability

The reality of production control

- Producer uses a production control system to determine if the mean strength from the test data is the same as the target strength
- Where this is shown not to be the situation, the mix proportions are adjusted
- There are various methods for doing this and the most popular system in the UK is the Cusum system

Cusum

Target strength	Actual strength	Difference	Cusum
40	43	+3	+3
40	38	-2	+1
40	38	-2	-1
40	42	+2	+1

The reality of production control

- The main reason for the actual strength not being the same as the target strength is changes in constituent materials, particularly changes in cement strength
- The changes are step changes
- Target strength set so that 'normal changes in constituent materials will not lead to non-conformity of strength

The reality of production control

- Essential that the producer can detect real changes in strength as quickly as possible
- Early strength data used to predict 28 day strength
- Problems with the stability of the early: 28 day relationship if accelerated or 3- day strengths are used (7 day strength is the UK norm)

The reality of production control

- Ready-mixed plants produce many concretes using the same materials
- A change in performance of a constituent material will effect all concretes made with that material
- Producer combines concretes into families so that real changes can be detected more rapidly (more on this in the next module)

The reality of production control

- The implication of this reality is that there will be a time delay between a change in quality occurring and it being detected by the producer
- A producer will select a conformity period that allows a change to be detected and corrected so that the average of all the data in the assessment period passes the criterion for mean strength

The reality of production control

- Concrete produced on a single day or over a short period of time is unlikely to have the same characteristics as the population used for the conformity evaluation
- Identity testing assumes it does


Concrete families
10.20 – 10.50

Benefits of using families

- Detection of significant changes in concrete strength more rapidly than individual concretes
- Makes efficient production control possible
- Makes conformity of a large number of concretes practical and economic

Definition of concrete family

Group of concrete compositions for which a reliable relationship between relevant properties is established and documented (BS EN 206-1)

BASIC STEPS

- Select families
- Select Reference Concrete (one per family)
- Establish relationships
- Mix selection
- Transposition of data from the tested concrete to an equivalent value of the Reference Concrete

BASIC FAMILY

- Cement of one type, strength class and source
- Demonstrably similar aggregates and type 1 additions
- All consistence classes
- With or without water reducer
- Limited range strength classes

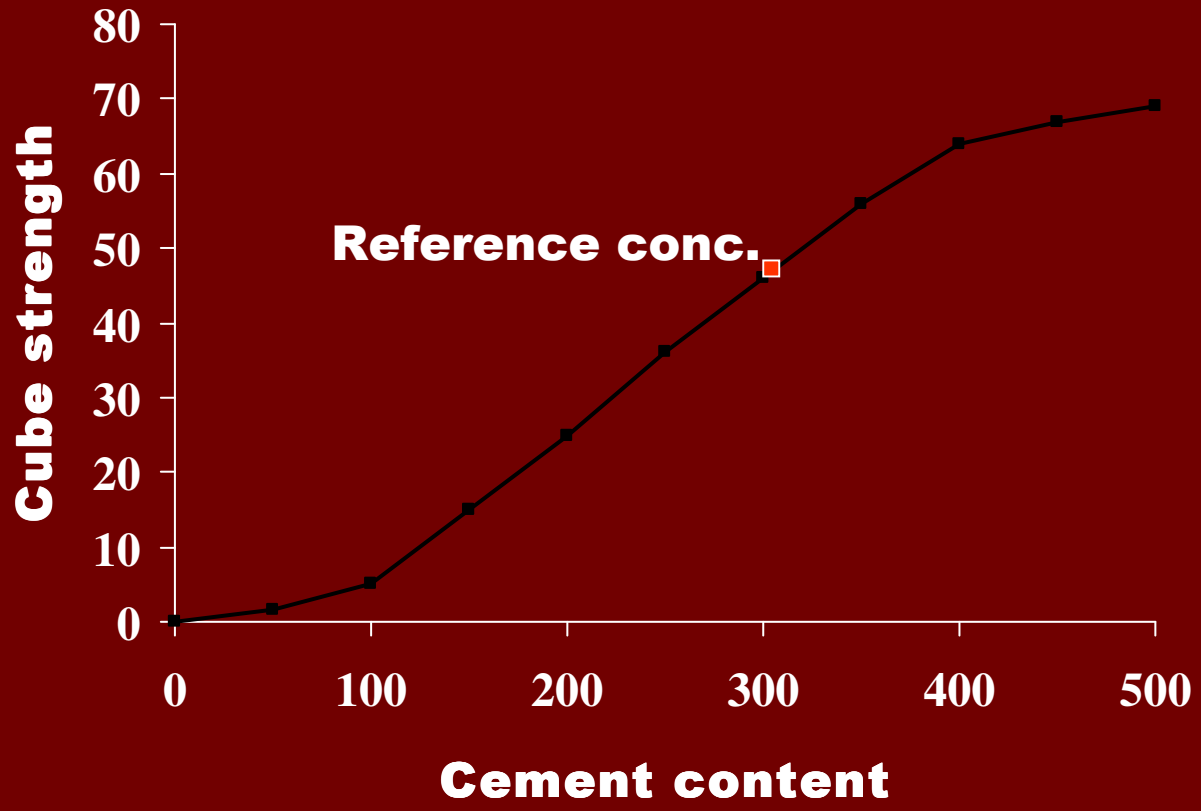
ESTABLISH RELATIONSHIPS OBJECTIVE

To establish the relationship between every concrete within the family and the Reference Concrete for the purposes of mix selection, transposition and mix adjustments

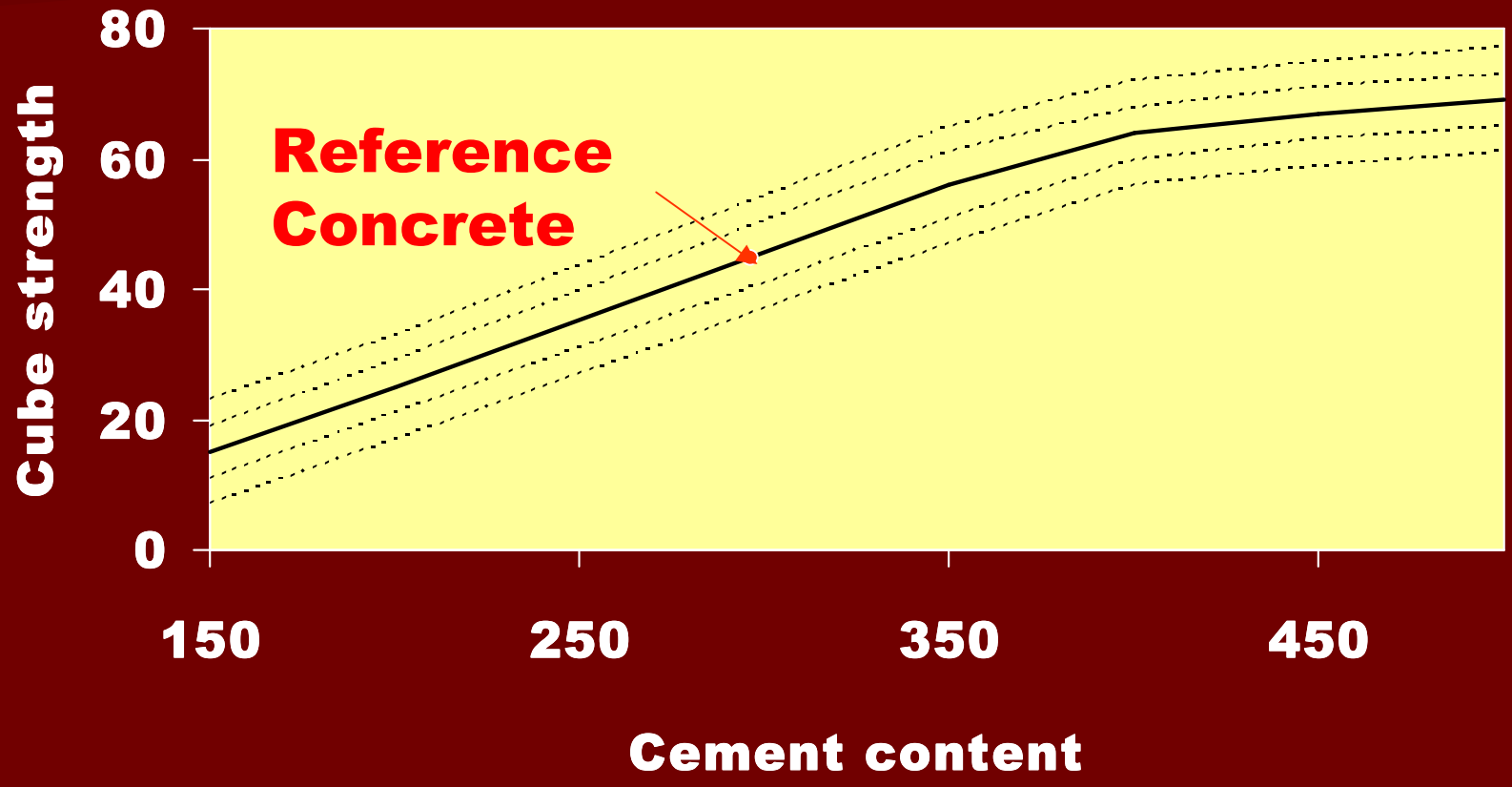
Methods for establishing relationships

- Trial mixes (Annex A of EN 206-1)
- Previous production data
- Theory
- Combination of the above

Primary relationships



TRANSPOSITION



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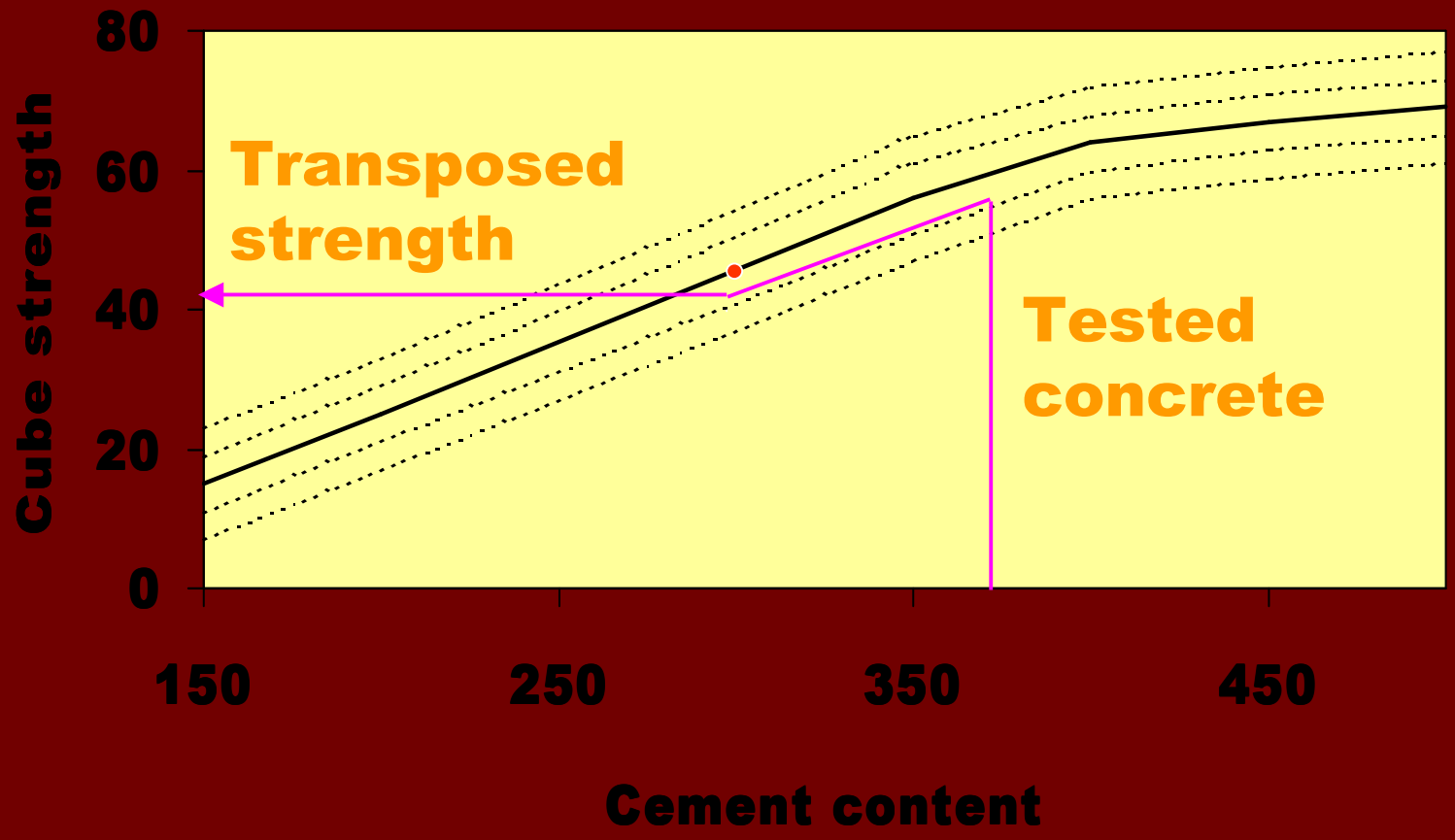
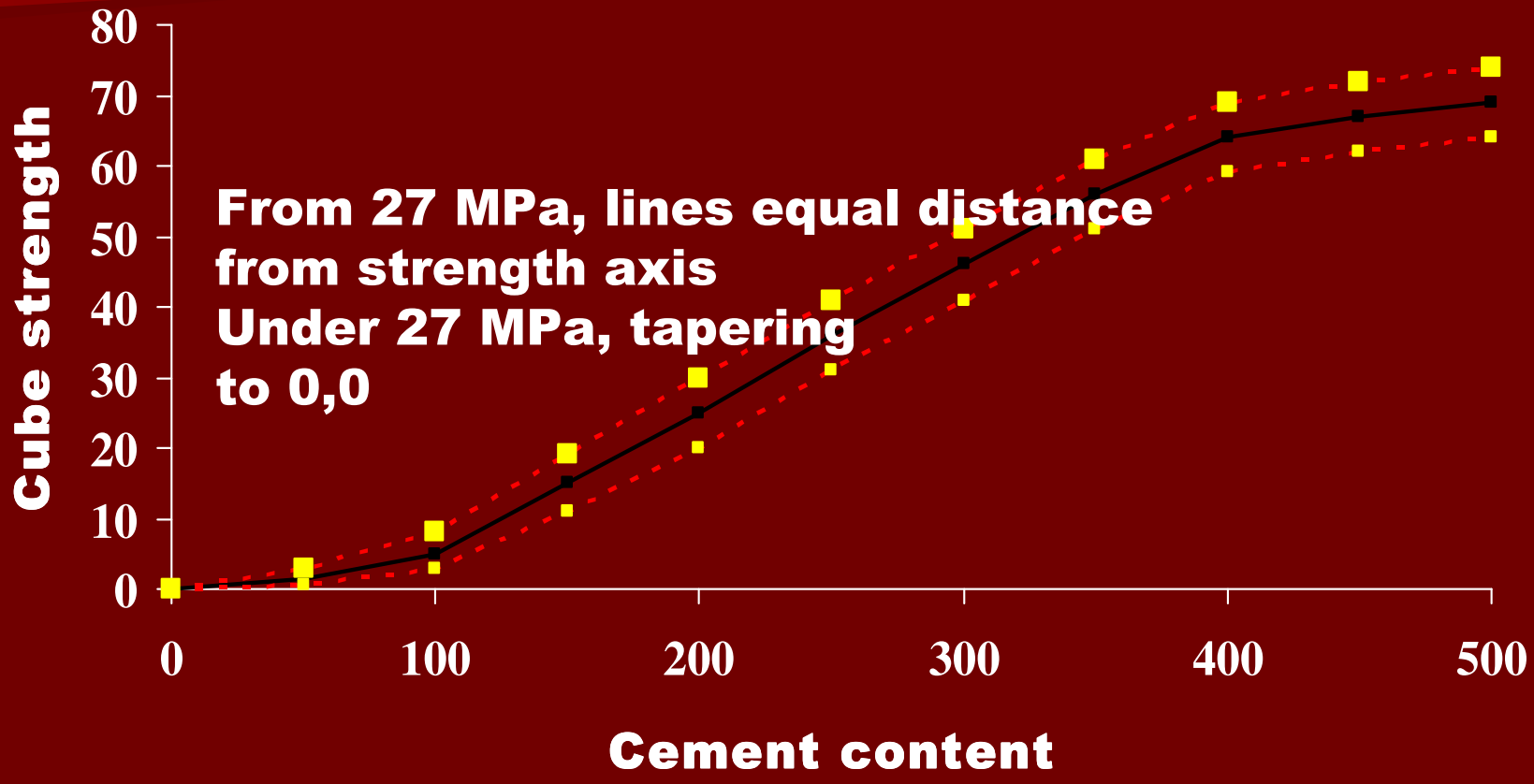


Simple method



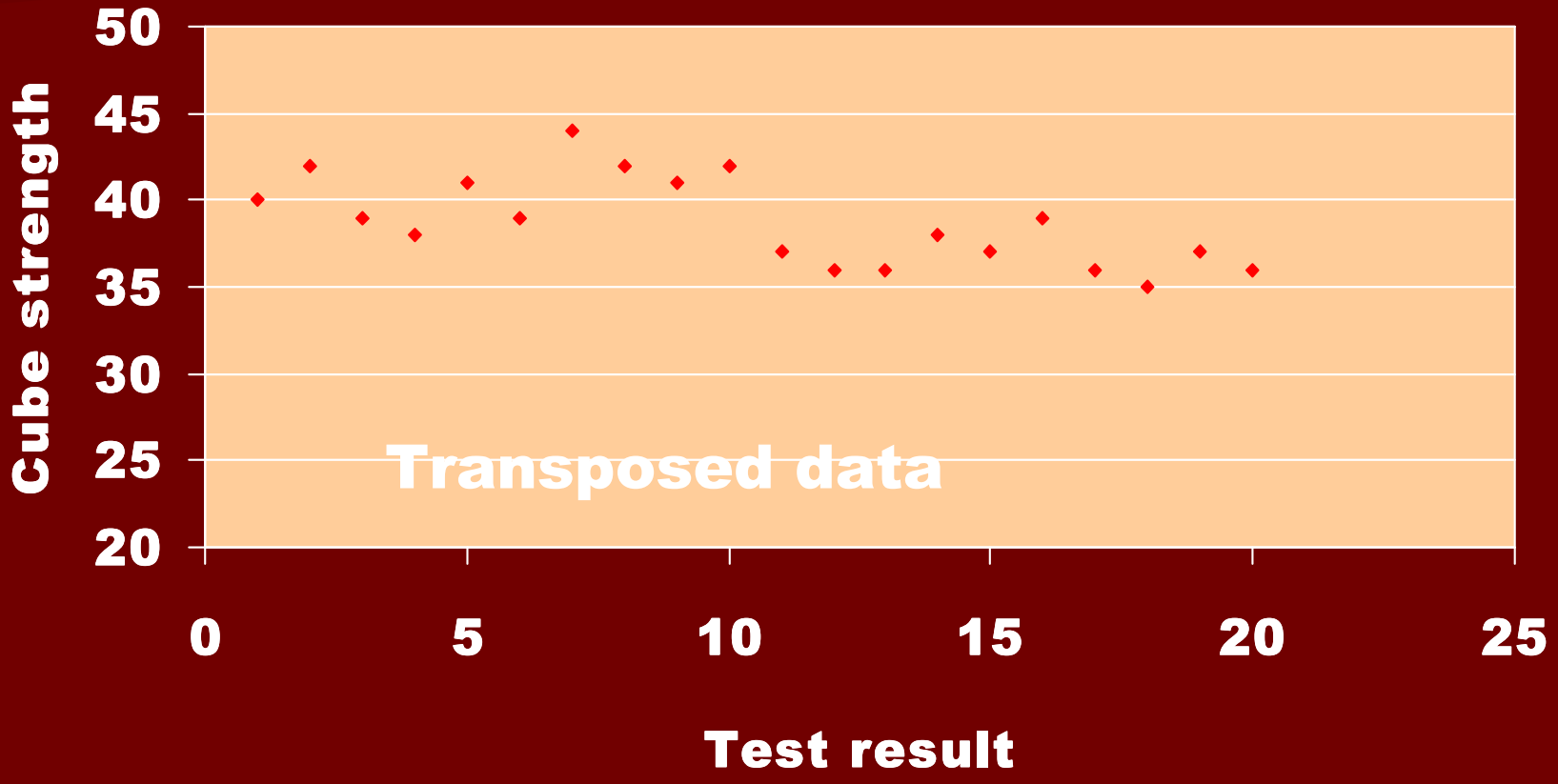
Secondary relationships

- Different target consistence
- Range of aggregate sizes
- Water reducing admixture
- Range of ratios of sand to coarse aggregate

Production control

By combining data into families, the time at which significant, real changes in the strength are detected can be significantly shorter

Production control - simple system



Conformity and identity testing

11.15 – 11.45

Conformity

Formalised procedure undertaken by producer to verify that the claims made on the delivery ticket are valid

Replaces BS 5328 compliance testing

Conformity control

- By producer
- Applies to specified properties in BS 8500 and limiting values

Conformity control

- Based on test data obtained during the assessment period
- Producer selects and defines the assessment period
- Not greater than 1 year
- Can be different for different aspects of conformity
- Assessment period can be based on a combination of number of results and time

Place of sampling

- Where relevant properties and composition do not change significantly between place of sampling and place of delivery
- Therefore sampling at plant permitted

There are benefits and disadvantages with plant sampling

Strength conformity

- Classified as initial production and continuous production
- Continuous production when 35 results obtained
- If production of a concrete or concrete family has ceased for over 1 year, initial production rules apply

Strength conformity

- Assessed on individual concretes and/or families of concretes
- Normal-weight and lightweight concretes cannot be in same family
- Concrete >C55/67 and >LC55/60 excluded from family concept

Strength conformity

- Other concretes permitted to be grouped into families
- Need to prove relationships between family members
- Guidance on family membership in BS EN 206-1, Annex K (not normative)
- Use of concrete families is well established in the UK

Example

C28/35 specified

Minimum characteristic cube strength required is 35 N/mm^2

Conformity criteria
Initial production

Individual criterion, $f_{ci} \geq f_{ck} - 4$

Example, $f_{ci} \geq 35 - 4 = 31$ N/mm^2

Mean of 3 consecutive test results $\geq f_{ck} + 4$

Example, $f_{cm3} \geq 35 + 4 = 39$ N/mm^2

Conformity criteria
Initial production

- Applied as consecutive groups of 3 non-overlapping results or as a running mean of 3
- Criteria developed on basis of non-overlapping results

Conformity criteria
Continuous production

Individual criterion, $f_{ci} \geq f_{ck} - 4$

This is the most important of the criteria

Mean of "n" tests $\geq f_{ck} + 1.48\sigma$ where $n \geq 15$

Example, $f_{cm} \geq 35 + 1.48x4 = 41$ N/mm^2

Continuous production

- Producer can select to apply as non-overlapping results or as overlapping results
- Criteria based on non-overlapping results

Conformity criteria Continuous production

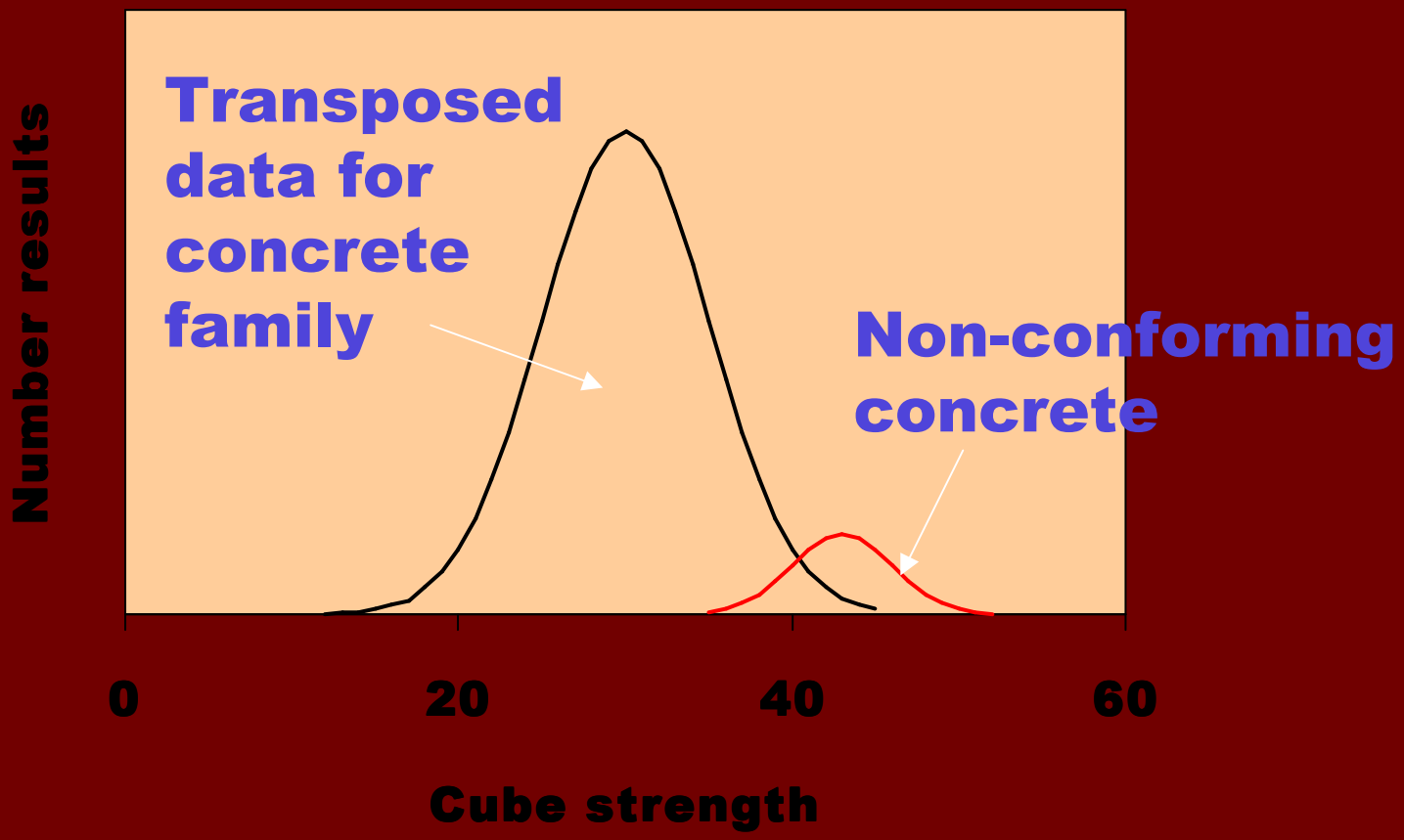
Where families are used:

- Individual criterion is unchanged
- Mean Ref. Conc. $\geq f_{ck} + 1.48\sigma$
- Confirmation criterion (not part of conformity, but check prior to assessing conformity)
- Assessment of relationships (not part of conformity)

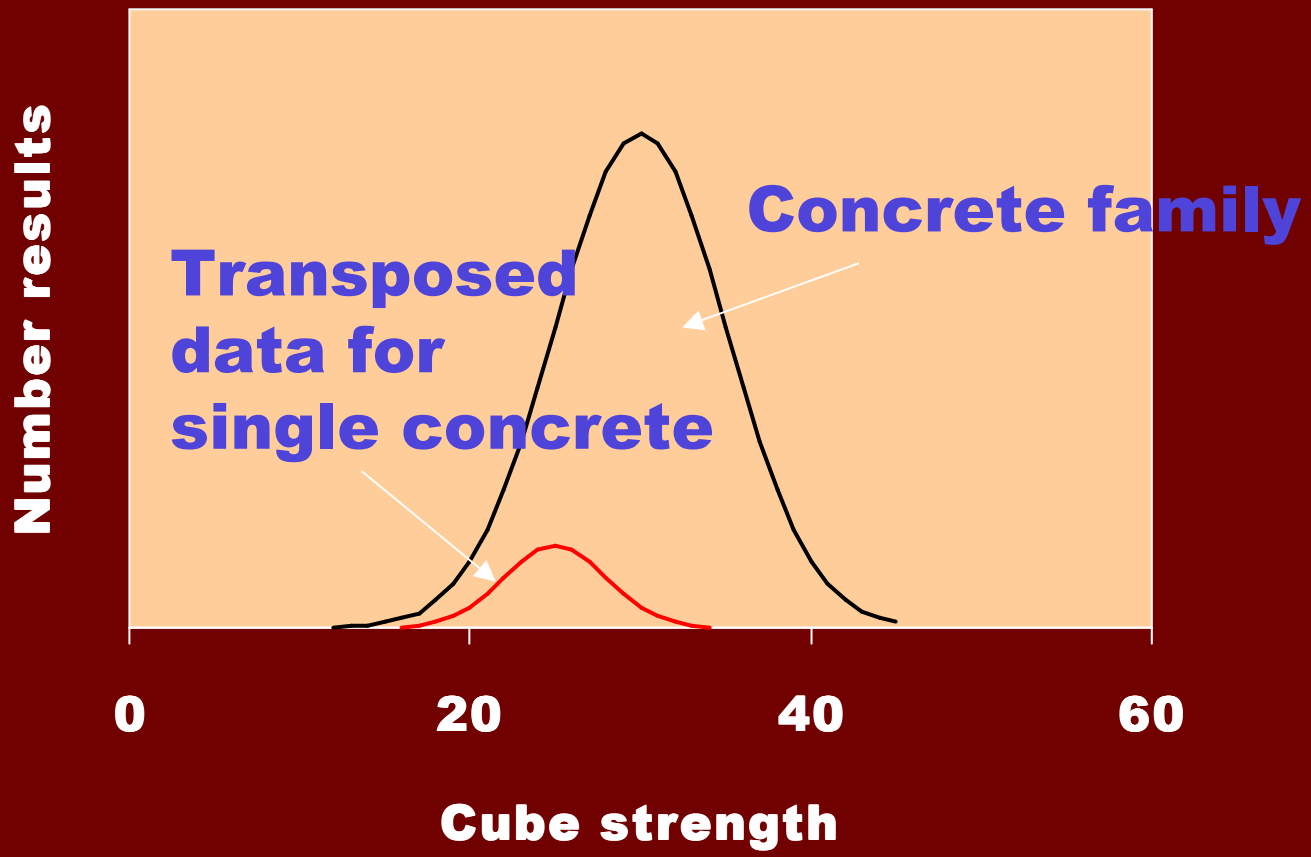
Confirmation criterion

Number test results	f_{cm} greater than or equal
2	f_{ck} –1.0
3	f_{ck} +1.0
4	f_{ck} +2.0
5	f_{ck} +2.5
6	f_{ck} +3.0

Reason for confirmation criterion



Reason for confirmation criterion



Consequences of the conformity criteria

With 15 results, there is a 30% probability of rejecting a population that just achieves the specified characteristic strength

Other properties

- A different approach to conformity is applied
- Method of attributes
- Most results are required to fall within the class limits or tolerances on target value
- In addition minimum and/or maximum limits for individual batches
- Explained with an example: slump

Conformity of slump

- Most results are expected to fall within the class limits given in BS EN 206-1, Table 3
- A few results are permitted to be outside these limits, but within values given in BS EN 206-1, Table 18

Slump classes (Table 3)

Class	Slump in, mm (Class limits)
S1	10 to 40
S2	50 to 90
S3	100 to 150
S4	160 to 210
S5*	≥ 220

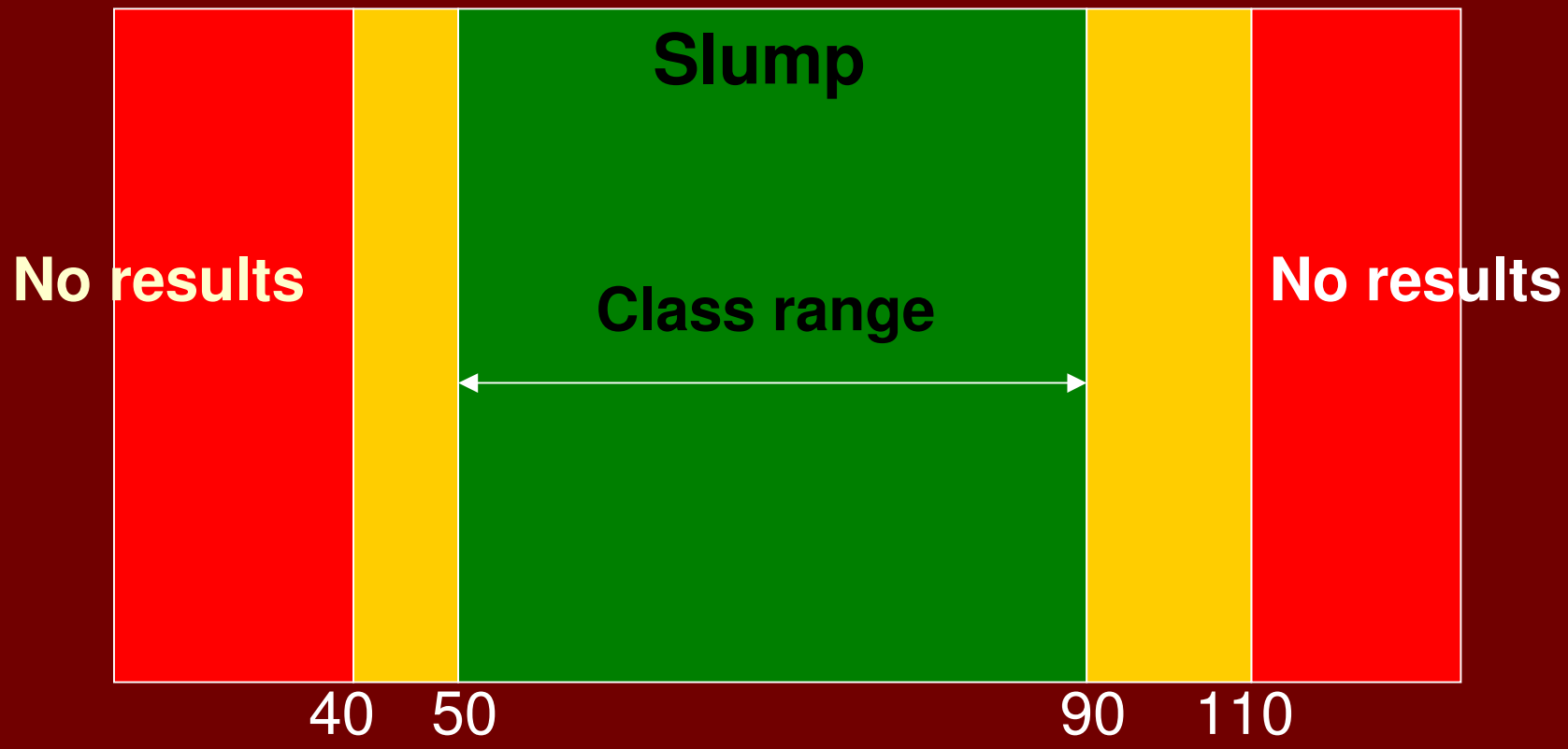
Example

For slump class S2, the class limits are 50 to 90mm

Maximum deviation of single test result (Table 18)

	Lower limit	Upper limit
Main discharge	**- 10**	**+ 20**
Initial discharge	**- 20**	**+ 30**

Example Slump class S2
Main discharge



Extract Table 19b
Applies to Slump

Number results	Acceptance no.
1 – 2	0
3 – 4	1
5 – 7	2
8 – 12	3
13 - 19	5

Similar approach to conformity of

- Density
- w/c ratio
- Cement content
- Air content

Declaration of conformity

This will be to BS 8500-2

The amendment to BS 8500-2 requires conformity to requirements in BS EN 206-1, therefore conformity to BS 8500-2 includes conformity to BS EN 206-1

Indicated non-conformity

Where confirmed non-conformity not obvious at time of testing, producer shall inform specifier and user

Non-conformities obvious at delivery/testing e.g. consistence, shall be either accepted or rejected there and then

Non-conformities not obvious at delivery include strength, maximum w/c ratio and minimum cement content

Indicated non-conformity

Producer will check test data for validity and whether they were entered correctly into the system

Producer will identify the cause of non-conformity, the non-conforming concretes and the period of non-conformity

Non-compliance with production control procedure

The concrete will only be declared as non-conforming where this failure to comply also leads to a non-conformity with respect to BS EN 206-1 clause 8 or the specification for the concrete

In all cases, the producer is required to review the reason for non-compliance with their procedures and take appropriate action

Actions in the case of non-conformity

If the non-conformity was result of adding water or admixture on site, producer only takes action if they authorized this addition

Third party certification

Strongly recommended

Provides independent audit by experts that conformity was undertaken correctly by the producer and that any non-conformities were reported correctly

Identity testing

- Not part of conformity
- Undertaken by specifier or user
- Confirms that a defined volume comes from a conforming population
- Requirements for strength given in BS EN 206-1, annex B
- Requirements for slump, flow and air content given in BS 8500-1, annex B

Identity testing

- Criterion for slump, flow and air content are same as conformity testing of an individual batch
- Individual criterion for strength same as that for conformity testing,

$$f_{ci} \geq f_{ck} - 4$$

Identity testing - cube strength
Mean strength of 'n' results

n	Mean of "n" results
1	Not applicable
2 – 4	$\geq f_{ck} + 1$
5 - 6	$\geq f_{ck} + 2$

Identity testing is recommended for

When there is doubt about the quality of a batch

For spot checks on the producer

For special concretes, e.g. very high strength concrete

Routine identity testing is rarely needed

Specifier may need strength tests for other purposes, e.g. formwork striking, prestressing


The future (ISO 22965)
11.50 – 12.20

Background

- ISO standard is based on EN 206-1
- EN 206-1 does not follow recent CEN guidance on conformity
- ISO standard is compatible with the CEN guidance
- New development is in Option B, which requires the producer to keep production in a state of statistical control

Conformity of strength

- In ISO, it was possible to agree the approach, but not the values
- If no values are given in the National Annex, default values are given
- These default values are the same as those in EN 206-1 for Option A
- The default values for Option B are based on the old QSRMC requirements

Conformity of strength

- Individual values
- Conformity over an assessment period
- Option A: Non-overlapping groups of three
  - Applies to initial production
  - Applies where production control is basic

Individual values

- Default values

$$f_{ci} \geq f_{ck} - 4$$

- Same as EN 206-1
- Applies to both cubes and cylinders
- Non-conformity leads to rejection of batch

Option A

- Non-overlapping groups of three
- (Does not permit overlapping groups)
- Does not permit the use of concrete families except where it is a precursor to Option B
- Default criterion

$$f_{cm3} \geq f_{ck} + 4$$

Option B

- No conformity criterion for a group of results
- Requirement to keep production in a state of statistical control
- Specific requirements for production control system in ISO DIS 22965
- Visionary approach

Production control systems

- Purpose is to detect when the expected values are not being achieved
- Need to separate out trends from normal variability
- Many systems available
- In UK, Cusum is widely used

Production control systems

- Contain a ‘warning limit’ and an ‘action limit’
- Need system to determine if:
  - The mean strength is being achieved
  - The standard deviation has changed
  - The early:28 day strength ratio has changed

Production control systems

- Upper and lower limits needed
- For strength, specifier is only interested if the strength is less than expected, but for commercial reasons the producer is interested in knowing if the strength is higher than expected

ISO requirements for system

- System for predicting 28 day strength from early strength testing
- In UK normal to use 7 day strength data
- Our experience is that 3 day and accelerated test data are not stable

ISO requirements for system

- Continual monitoring of achieved mean strength, standard deviation and correlation between early and 28-day strength

ISO requirements for system

- Target mean strength set at not less than (f_{ck} + k) where default value of k =2σ
- If the standard deviation is 4 N/mm^2, this gives a margin of 3σ from the minimum acceptable strength
- Default value of the minimum standard deviation of 3.0 N/mm^2 (low standard deviations increase risk of non-conformity)

ISO requirements for system

- Initial standard deviation based on at least 35 results taken over a period not exceeding one year
- Same as in EN 206-1
- Strongly recommended, but nor required, that concrete families are used for production control

ISO requirements for system

- System sensitivity defined
- Real changes in mean strength $\leq 0.5\sigma$ over an average run length of 35
- Standard deviation changes as in EN 206-1
- Cusum will satisfy these requirements

ISO requirements for system

- Requirement to take action when the actual mean strength is more than 0.5σ below target mean strength
- Requirement to take action where

$$s_{15} > 1.37\sigma$$

- When the strength is higher or sd lower than expected, action is optional


Thank you for your attention