Reducing carbon and cost by using the real, tested strength of steel reinforcement

1. Introduction

The most commonly specified characteristic yield strength of steel reinforcement is 500MPa. However, publicly available research suggests that the characteristic yield strength of much of the reinforcement in the UK exceeds 500MPa. To us, that presented an opportunity to save carbon and cost for HS2's Old Oak Common Station (where we are structural designers, partnered with WSP).

Our study reviewed material testing data for steel reinforcement recently supplied to the UK to prove the feasibility of adopting a higher yield strength for the design of reinforced concrete elements. We found that an increased yield strength of 520MPa could be adopted without altering the design process significantly or compromising procurement strategies or programme. We collaborated with CARES and worked closely with the client and contractor teams to successfully implement our findings at Old Oak Common Station, achieving real cost and carbon benefit.

2. Quality assurance for steel reinforcement

Reinforcement manufacturers are required to conduct quality assurance tests to meet the requirements of BS4449 (the British Standard for weldable reinforcing steel). Some of the tests must be witnessed by an independent organisation and samples sent to an independent laboratory for testing. The results of the tests are submitted to the third-party certifier, if used.

The results of the quality assurance tests are used to calculate the mean yield strength and the standard deviation of the yield strength. The characteristic yield strength of the reinforcement is then calculated.

3. Our research

CARES is one of the foremost reinforcement certification programmes in the world. In the UK, "CARES certified reinforcement" is a common requirement in materials specifications on construction projects. We worked with CARES to obtain anonymised long-term quality level submissions (standard deviation and mean yield strength test results) for reinforcement sold in the UK between 2017 to 2019, including results of 284,000 yield strength tests.

We undertook a desk study analysis of the CARES data, considering data sets by mill, bar diameter, steel grade and format (bar or coil). From this, we established the mean yield strength, the standard deviation of the yield strength and the characteristic strength of each data set.

We also reviewed whether the data received fitted a normal distribution, a prerequisite of the formulas provided in BS 4449.

3.1. Our Findings

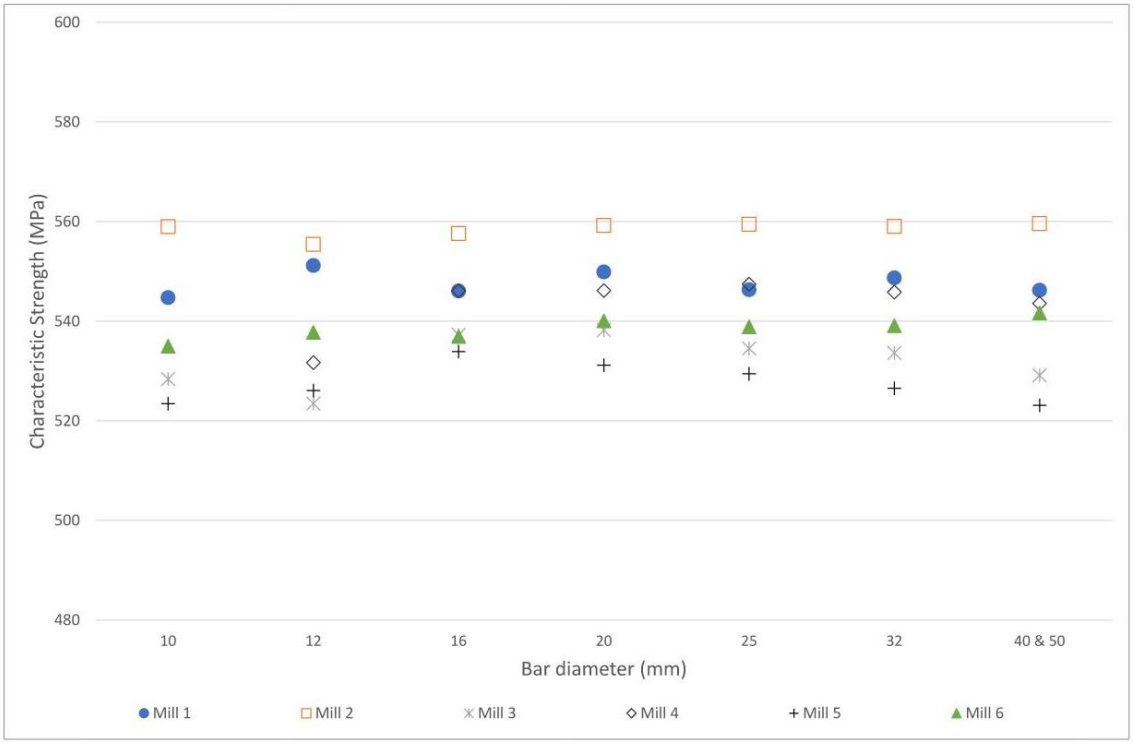

Figure 1: Estimated characteristic yield strength, $\bar{x} - ks$, (Class B & C)

- A large majority of the data sets reliably exceed the BS 4449 strength requirements by a significant margin.
- The strength properties of reinforcement vary between mills and, to a lesser extent, between reinforcement of different diameter, class or format (bar or coil) from each mill.
- A large majority of the data sets follow a normal distribution of the yield strength.
- Of the data sets which are not consistent with samples taken from a population with a normal distribution, most are skewed so that it is likely to be conservative to assume a normal distribution, although a small minority were not.

3.2. Conclusions

From this data, we drew the following conclusions about using increased yield strength properties at Old Oak Common Station:

- The majority of mills reliably supply reinforcement with strength properties which exceed the requirements of BS 4449.
- The highest characteristic yield strength properties for any single mill were[1]:
  - Characteristic yield strength 550 MPa
  - Mean yield strength: 562 MPa
  - Standard deviation of the yield strength: 11 MPa

- To maintain the ability to obtain competitive prices from the market for steel reinforcement, the following specification properties can be used (these will not require most mills to make any changes to production methods) [1]:
  - Characteristic yield strength 520 MPa
  - Mean yield strength: 545 MPa
  - Standard deviation of the yield strength: 22 MPa
- The conformance criteria for quality assurance tests must be modified if higher strength properties are specified.
- It must be demonstrated that the test data population is consistent with a normal distribution, or else that it is conservative to assume a normal distribution.

3.3. External Review

Our proposals for using an increased yield strength and the analysis methodology were reviewed by Dr John Orr (University Lecturer in Concrete Structures at Cambridge University), Paul Jackson (Technical Director at Ramboll and co-author of "Partial safety factor for reinforcement" (2016)), and Guillermo Gabrielli (Senior Specialist at WSP Canada). The detailed analysis of the results received from CARES was not included in their reviews.

4. Implementing the research at Old Oak Common Station

4.1. Design method

Adopting a higher characteristic yield strength is relatively simple in most design software by manually inputting the design value for the reinforcement yield strength. In strength-governed elements, this achieves a reduction in the area of reinforcement required proportional to the increase in strength.

An additional method studied and reviewed, but not implemented at OOC, is reliability analysis[2]. The approach requires the mean and standard deviation of all the section material and geometrical parameters to be identified to calculate the section moment resistance. In many cases, the reinforcement properties govern the statistical parameters of the section moment resistance and so substantial further benefit can be gained by adopting 'improved' properties. This is effective in sections acting principally in bending and with depth greater than 300mm. It requires additional design effort so is most practical in elements for which there is a substantial potential saving (e.g. large, highly reinforced or much-repeated elements).

4.2. Procurement

The specified characteristic yield strength can be tuned to match the procurement needs of the project. If a project needs many mills to be able to supply to it (eg. to reduce project risk), lower yield strength properties can be specified. Negotiating procurement from individual mills, will enable higher yield strength properties to be specified and will deliver larger cost and carbon savings.

Note that modifying the specified yield strength properties as proposed in this paper does not affect the manufacturing or quality assurance processes of the mills and requires only minor amendment to the acceptance criteria of the assurance process. Furthermore, if reinforcement were to fail to meet the specified increased strength criteria for Old Oak

[1] The apparent inconsistency in the values is due to enveloping parameters across data sets. Data sets with higher mean yield strengths tend to have larger standard deviations (ie. higher, broader distributions) and those with lower means tend to have smaller standard deviations (ie. lower, narrower distributions

[2] As defined in Eurocode 0 Annexes C and D and the UK National Annex

Common (or any project adopting modified yield strength properties), it may still meet the BS 4449 conformance criteria for 500 MPa reinforcement (all the data analysed did) and be suitable for use on other projects.

4.3. Secondary effects

The study also considered secondary issues. These included compatibility of ‘higher strength’ reinforcement with pull-out bars, shear studs, punching shear reinforcement systems and couplers, required lap and anchorage lengths and crack and deflection control.

We found that increasing the yield strength affects several other parameters (eg. anchorage and lap lengths increase broadly proportionally), but is not incompatible with them. However, no benefit is achieved in proprietary products without additional testing .

The knock-on effects of increasing the yield strength of reinforcement do need to be carefully considered. Implications can be followed in the Eurocode and none have precluded implementation of the increased yield strength at Old Oak Common Station.

4.4. Checking conformance for the project

To enable enhanced project quality assurance processes, the conformance test results must be provided to the project in good time for review . Recent improvements in quality assurance technology, such as CARES’ Cloud, makes this an inherent part of reinforcement procurement.

5. Outcomes

For Old Oak Common Station, the following specification value was adopted:

- Characteristic yield strength 520 MPa

This value was set to allow the project to obtain competitive prices from the market for steel reinforcement.

This will save up to 4% of the reinforcement in the strength-governed elements on the project. Whilst this looks a marginal saving, it includes almost 2km of a basement box retaining wall and will deliver real reductions in cost and CO2e.

6. Applying elsewhere

To successfully adopt an increased yield strength, client, contractors and designers must together confirm the design strength to be adopted. This is done by working directly with mills, or else third-party certification schemes, to balance procurement considerations and savings. The modified acceptance criteria must then be included in the materials specification. Standard design methods can be used, or else increased benefit derived from a reliability analysis, with attention given to secondary issues including those discussed above.

Our study has demonstrated that reinforcement manufacturers are able to reliably supply steel with increased yield strength properties. Discussions with CARES suggest that, with sufficient demand, many mills could economically increase their yield strength properties.

This study challenges industry habits and highlights an opportunity to regularly save both cost and carbon. The 4% saving at Old Oak Common Station sets a precedent which wider adoption can increase, saving unnecessary cost and carbon.