INFLUENCES OF LOCALLY PRODUCED AND IMPORTED REINFORCING STEEL ON THE BEHAVIOUR OF REINFORCED CONCRETE MEMBERS

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SUMMARY

The design of reinforced concrete members is heavily influenced by the material properties and characteristics of the longitudinal and transverse reinforcement. A growing number of imported reinforcing steels are being used in the construction industry in New Zealand. While the material properties of each of the reinforcing steels may comply with the requirements of AS/NZS 4671, their influence on the load and deformation characteristics of reinforced concrete members is not fully understood. There is also a growing concern that engineers are not applying suitable due diligence to confirm compliance with AS/NZS 4671. This paper highlights areas of concerns with the use of non-compliant imported reinforcement in the design of reinforced concrete members and provides guidance on means to enforce compliance with AS/NZS 4671. The impact of imported reinforcing steel on the behaviour of reinforced concrete members is investigated and the preliminary results from a long term testing of material properties of Pacific Steel reinforcement are presented.

INTRODUCTION

The behaviour of a reinforced concrete member when subjected to imposed loading is heavily influenced by the mechanical properties of the steel reinforcement and the interaction of steel reinforcement with the concrete. Steel reinforcing used in New Zealand is required to comply with the requirements of AS/NZS 4671: 2001 [1]. This standard provides requirements for both the material and mechanical properties of the reinforcing steel.

Design engineers are coming under increasing pressure from contractors and developers to permit cheaper alternative reinforcing steels, other than New Zealand manufactured steel, to be used with conforming design solutions. Typically these alternatives are found after the contracts have been let and the design completed. Often the reinforcement has not been tested nor has it been shown to be compliant with the requirements of AS/NZS 4671.

The use of imported reinforcement which is non-compliant with AS/NZS 4671 could significantly alter the performance of the structure in which it is used [2,3,4]. Often this reinforcement has yield and ultimate strengths which are outside the limitations which have been considered by the materials standards, such as the New Zealand Concrete Structures Standard, NZS 3101 [5].

The onus for compliance of reinforcing steel with AS/NZS 4671 is on the contractor, the steel processor and the steel manufacturer. However, design engineers can transfer the liability of the use of non-compliant reinforcing steel to themselves by signing Producer Statements for Design without acknowledging the use of non-compliant reinforcement [6].

This paper provides a summary of the requirements of AS/NZS 4671 and highlights a series of procedures that design engineers can use to enforce compliance. A series of design related issues with the use of imported reinforcing steel are raised. The paper also presents the results obtained from an ongoing study by Pacific Steel into the material properties of reinforcing steel manufactured in New Zealand.

AS/NZS 4671: 2001

AS/NZS 4671: 2001, “Steel Reinforcing Materials”, has resulted in the introduction of three classes of Grade 500 reinforcement into the New Zealand marketplace. Grades L, N, and E, are designated for Low, Normal or seismic (Earthquake) ductility respectively.

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The intent of AS/NZS 4671 is to benefit the construction industry by providing more uniform product with tighter conformance requirements and produce more reliable member performance as a result of the clarification of minimum ductility levels [1,6].

The main body of AS/NZS 4671 provides requirements on the classification and designation of the reinforcement and on the manufacturing methods. Limitations are also established for the chemical, mechanical and dimensional requirements of the different reinforcing steel grades.

The characteristic mechanical properties of the Grade 500 reinforcing steel from AS/NZS 4671 are reproduced in Table 1.0 above. The variables $R_{ek,L}$ and $R_{ek,U}$ are the lower and upper characteristic yield stress of the material respectively, $R_m$ is the ultimate tensile strength, and $A_{gt}$ is the strain in the steel corresponding to the maximum stress in the bar, also defined as the uniform elongation.

The performance requirements for Grade 500N are significantly lower than for Grade 500E. Grade 500N has an allowable uniform elongation ($A_{gt}$) which is half that of Grade 500E. In addition both Grade 500L and 500N do not have an upper limit to the ratio of the ultimate tensile stress to the yield strength ($R_m/R_y$). These factors, when coupled with the broad range of allowable yield stresses, allows reinforcement with a very diverse range properties to be used in the construction industry in New Zealand.

Appendix A of AS/NZS 4671 provides a means for demonstrating compliance with the Standard. Four methods are provided, as listed below:

- Evaluation by means of statistical sampling.
- The use of a product certification scheme.
- Assurance using the acceptability of the supplier’s quality system.
- Other such means proposed by the manufacturer or supplier and acceptable to the customer.

The requirements of the manufacturing control for all aspects of production, from steel melting to the dispatch of end products, are provided in Appendix B. Requirements are provided for the sampling and testing of reinforcing steel where the long term quality control is both known and unknown. For imported reinforcement of unknown quality, compliance is assessed in accordance with section B7, “Material Not Covered by Long Term Quality Level”. This section requires a minimum of 15 tensile tests and 2 chemistry tests to be undertaken on batches of no more than 100 tonne. Should more than 2 of test results be found to fall outside of the allowable bounds, set in the Standard, a further 45 samples are required to be tested. Very good guidance is provided in Appendix as to how the results should be statistically analysed and what information should be presented in the test reports.

Reinforcing steel which is from a source of known long term quality, such as steel provided by Pacific Steel, is subjected to a less rigorous testing regime, reflecting the increased confidence in the long term properties of the reinforcement.

Appendix C of AS/NZS 4671 provides detailed testing procedures for determining the mechanical and geometric properties of the reinforcement. This section is additional to the requirements listed in the main body of the Standard.

Appendix D outlines information which should be supplied by the purchaser of the reinforcement at the time of purchase. Appendix D also provides guidelines for the issue of test certificates by the steel producer or steel processors as a means of showing compliance with the Standard.

**Compliance with AS/NZS 4671:2001**

Designer engineers are often taking on unnecessary liability by providing Producer Statements for Design on construction projects.

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### Table 1.0 Characteristic Properties of Reinforcing Steel

<table>
<thead>
<tr>
<th>Property</th>
<th>500L</th>
<th>500N</th>
<th>500E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Stress</td>
<td>$R_{ek,L}$</td>
<td>≥ 500</td>
<td>≥ 500</td>
</tr>
<tr>
<td></td>
<td>$R_{ek,U}$</td>
<td>≤ 750</td>
<td>≤ 650</td>
</tr>
<tr>
<td>Ratio</td>
<td>$R_m/R_y$</td>
<td>≥ 1.03</td>
<td>≥ 1.08</td>
</tr>
<tr>
<td>Uniform Elongation</td>
<td>$A_{gt}$ (%)</td>
<td>≥ 1.5</td>
<td>≥ 5.0</td>
</tr>
</tbody>
</table>
which have been undertaken with reinforcement that is non-compliant with AS/NZS 4671 or which is not fit for purpose, such as the use of Grade 500N reinforcement in a design which requires high plastic deformations in members [6]. Even though AS/NZS 4671 provides a series of procedures which can be used to show compliance with the standard, these procedures are often misunderstood or ignored by designers.

Design engineers are often provided with test results from one or two samples of steel tested at a reputable testing agency as a means of compliance with AS/NZS 4671. The information contained in the test reports is usually limited (typically just the tensile strength is cited) and little information is provided as to the source or sampling technique used to obtain the samples. This limited form of testing does not comply with the intent or requirements of AS/NZS 4671 and should not be accepted as a means of compliance. However, ill informed design engineers often accept limited test reports as proof of compliance.

Compliance of reinforcement with AS/NZS 4671 can be obtained using the relevant sections of Appendix A, B, C and D. However, Appendix A is an “informative” section only. It is believed that this classification makes Appendix A relatively ineffectively as a means of enforcing compliance because in a dispute either party may interpret it as non-binding. It is recommended that Appendix A not be relied on as a means of enforcing compliance with AS/NZS 4671. However, if necessary, Appendix A should be specifically referenced in the contract documents.

Appendix D of AS/NZS 4671 is also an “informative” section of the standard. This section makes an allowance for the use of a test certificate which shows “...test performed by the steel producer or steel processor for the purpose of establishing compliance with the appropriate material standard”. This form of self-certification is prone to misuse, as most mills would be capable of producing the required documentation without any consideration for the manner in which the results were obtained. It is recommended that designers be very cautious of using this form of product certification.

Appendix B is a “normative” section of the report and provides the most consistent means showing compliance with the standard. For the majority of imported reinforcing steel it will be necessary to undertake testing in accordance with section B7, “Material Not Cover by Long Term Quality Control”.

Achieving compliance with AS/NZS 4671 requires regular testing to determine the key material properties and chemical make up of the reinforcement [1]. This testing is neither complicated nor onerous. However it should be completed by an independent, reputable testing agency [2,3,4,6].

It is recommended that design engineers enforce the requirements of Appendix B when seeking to determine the compliance of imported reinforcing steel with AS/NZS 4671. By citing AS/NZS 4671 in the contract documents, Appendix B is automatically cited and becomes legally binding [6].

DESIGN ISSUES

The use of imported reinforcing steel is becoming more prevalent in the New Zealand construction industry. Designers are coming under increasing pressure from contractors and developers to permit these cheaper imported steels to be used with conforming design solutions. Typically these alternatives are found after the contracts have been let and the design completed.

The performance of a reinforced concrete member is heavily influenced by the material properties of the reinforcement [7, 8]. Given the wide variety of material properties of cheaper imported reinforcing steels it is not possible to directly substitute cheaper imported reinforcement into a conforming design without considering the implications on the behaviour of the members and structure as a whole, even when the imported steel complies with AS/NZS 4671 [2,3,4].

The following section highlights a series of design issues which can arise when imported reinforcing steel is substituted into a conforming design.

Bond Stresses:

The development and lapping requirements presented in NZS3101 were developed for reinforcing bars which develop tensile stresses under 556 MPa [9,10,11]. In certain locations, such as the curtailment of bars near plastic hinge locations in beams, or the lap between a starter bar and vertical reinforcement near the end of a wall panel it is possible for the stresses in the reinforcing bar to significantly exceed this value. Research completed at the Universities of Canterbury and Auckland found that there is the potential for loss of bond on reinforcing bars with yield strengths in excess of 550 MPa [10].

AS/NZS4671 allows grade 500N reinforcement to have yield strengths of up to 650 MPa and no
limitations on the ultimate capacity of the reinforcement. There is a high potential that imported reinforcing steel will have high yield strengths and may exceed the bond strength of the concrete [2,3].

It is recommended that all lap lengths used in concrete members produced with imported reinforcing steel which are not compliant with the long term performance testing requirements of Appendix B be calculated using a conservative estimate of the reinforcement yield strength of 650 MPa. This will effectively increase the lap lengths by 30% above those calculated using a lower characteristic yield strength of 500 MPa.

Ductility:
The majority of reinforced concrete structures in New Zealand are designed to be ductile under overload conditions by forming plastic hinges in the beam elements and at the bases of walls and columns [6]. Each plastic hinge zone must be capable of undergoing large amounts of inelastic deformation with little or no reduction in load carrying ability. If the longitudinal reinforcement used in the concrete member has a sufficiently large value of uniform elongation, $A_{gr}$, such as Pacific Steel Grade 500E, then the ultimate displacement of the member may only be limited by the maximum allowable inter-storey drift of the structure [8, 9].

Imported reinforcing steel which is non-compliant with AS/NZS4671 or compliant with Grade 500L and 500N classes have low allowable uniform elongation, $A_{gr}$. Reinforcement which has a uniform elongation capacity equal to the minimum values for Grade 500N steel will have ultimate displacement capacity approximately 50% smaller than an identical member constructed with Grade 500E reinforcement.

Structures which are designed to be elastic or nominally elastic will still require element to undergo inelastic deformations. In the topping concrete on precast concrete floors units it is common to place continuity reinforcement to provide deflection control and to reduce the mid-span moment in the precast prestressed concrete floor units. The continuity steel is required to undergo large inelastic strains at the Service Limit State [2,3,4,6].

Reinforcement placed near the ends of reinforced concrete walls will also be required to undergo large inelastic strains to achieve the design level loads, even in so called elastically designed walls.

Due to the reduced level of ductility in structures designed with Grade 500L and 500N steel, it is recommended that elements which require any form of ductility, either through seismic action, gravity moment redistribution, or imposed displacements be designed with Grade 300E or 500E as longitudinal reinforcement.

Flexural Overstrength:
The overstrength factor is defined as the ratio of the maximum strength of a concrete member, $M_{\text{max}}$, to the nominal strength of the concrete member, $M_{n}$. The nominal capacity is usually calculated using the lower 5th percentile yield strength of the reinforcement. The overstrength ratio is used to ensure that the strength of all other elements in a reinforced concrete structure are stronger than the maximum possible strength of the element that has been chosen to deform in an inelastic manner. The ability to accurately determine the maximum overstrength capacity of an inelastic member is the fundamental principal in "capacity design". A full description of the principles of capacity design are provided elsewhere.

NZS3101 provides guidance on determining the flexural overstrength of concrete members manufactured with Grade 500E reinforcement [5]. These guidelines were determined in a specific study undertaken by Pacific Steel Limited and are only valid for locally produced reinforcement Grade 500E reinforcement [2,3].

A conservative estimate for the overstrength factor for a reinforced concrete beam with imported reinforcing steel reinforcement can be calculated be dividing the maximum allowable ultimate stress of the reinforcement $R_{m}$ by the lower characteristic strength of the reinforcement used in the design (typically 500 MPa).

Fatigue
The fatigue strength of reinforced concrete is of interest for members that are subjected to repeat cyclic loading, such as heating and cooling cycles, repetitive wind loading and traffic loads [6]. The fatigue strength of a reinforced concrete member is highly dependent on the fatigue strength of the reinforcement.

Testing completed on the fatigue resistance of high strength hot rolled reinforcing steel indicated that the fatigue strength of the reinforcing steel with yield strengths in excess of 520 MPa were similar or greater than an identical samples with yield strengths of 450 MPa [6].

All of the steels tested had relatively large values of uniform elongation. Very little research has been completed on the fatigue resistance of high strength reinforcing steel with relatively low
uniform elongation capacity, such as Grade 500L and 500N. However it was observed after the Northridge earthquake that a large number of parking structures with concrete roofs had fractured all of the reinforcement tying the roof to the wall elements. In a number of buildings it was determined that the reinforcement had fractured before the earthquake. The probable cause of the fracture of the reinforcement was fatigue due to the heating and cooling cycles felt by the roof. The steel in these structures was cold drawn wire with similar properties to the Grade L reinforcement in AS/NZS 4671: 2001.

Due to the lack of information regarding the fatigue resistance of high strength reinforcement with low uniform elongation capacity it could be recommended that any element subjected to cyclic loads, such as thermal movements or traffic loads, should be constructed with either Grade 300E or 500E reinforcement.

Site Issues/Classification:
NZS3101 places severe restrictions on the use of Grade 500N and 500L reinforcement. However, a number of contractors are now enquiring about using Grade 500N reinforcement for "non-ductile members". This raises the issue of steel identification on a construction site and the consequences of misidentification [2, 3, 6].

Previously the only reinforcement used on a construction site in New Zealand was Grade 300, Grade 500 and the discontinued Grade 430. If a Grade 300 reinforcing bar was misidentified and placed into a yielding element designed for Grade 430 reinforcement, then the member would have a lower strength than calculated. This would not have resulted in the premature catastrophic failure of the element as both Grade 300 and Grade 430 have large uniform elongation capacities and the structure would have been capable of redistributing the applied loads.

With the introduction of three classes of Grade 500 steel onto the market place there is a possibility that both Grade 500N and 500E will be used on the same construction site. If a Grade 500N bar was misplaced into a primary yielding element instead of Grade 500E then the apparent design strength of the element would not significantly be affected, but the displacement ductility of the member would be severely reduced. The reduced level of ductility could result in the member failing prematurely thereby placing additional loads on the surrounding elements.

It is recommended best practise to limit the reinforcement used on a construction site to one ductility class (L, N or E) to avoid potential for misidentification on site, preferably class E as it is the most ductile and tolerant to miscellaneous sources of imposed strain.

LOCALLY PRODUCED REINFORCING STEEL

Reinforcement manufactured by Pacific Steel is fully compliant with AS/NZS 4671. Pacific Steel have ongoing quality control procedures and a proven track record of quality which allows their reinforcement to be subjected to the less stringent long term quality control requirements of AS/NZS 4671. However, Pacific Steel is proactive in the completion of testing and publishing of the results for use by the design industry. This ensures a high degree of confidence in the consistency of the locally produced reinforcement, both for mechanical and geometric properties.

A method of ensuring compliance with AS/NZS 4671 is to specifically include in the contract documents a clause stating that only Pacific Steel reinforcement should be used, unless the contractor specifically shows other alternative reinforcements are compliant with AS/NZS 4671 and that the reinforcement has similar material properties and is of a similar quality (regarding both mechanical and geometric properties) to the Pacific Steel reinforcement. This method allows the design engineer to design the structure with confidence in knowing the material properties of the reinforcement. If an alternative reinforcement is suggested by the contractor it will not alter the performance of the structure or require redesign by the engineer. This method of forced compliance has been adopted by Holmes Consulting Group.

CONCLUSIONS

1. All reinforcement used in the construction industry in New Zealand should be compliant with AS/NZS 4671.
2. AS/NZS 4671 has “informative” and potentially non binding recommendations. It is suggested that design engineers make specific reference to AS/NZS 4671 to ensure it is legally enforceable.
3. Design engineer should refrain from using the self certification allowances for mills outlined in Appendix D of AS/NZS 4671.
4. Due to the reduced level of ductility in structures designed with Grade 500L and 500N steel, it is recommended that all
elements that require any form of ductility, either through seismic action, moment redistribution, or imposed displacements be designed with Grade 500E as longitudinal reinforcement.

5. For certain regions in slabs, columns and wall elements, plastic elongation capacity for reinforcement is desirable. It is recommended that in these situations, reinforcement should be constructed from Class E reinforcement with the strict controls on the ratio of $R_m/R_e$ to ensure that there is reasonable yield penetration and a larger uniform strain capacity to resist the imposed displacements without fracturing.

6. To avoid site classification errors it is recommended that only one class of reinforcement is used on any construction site, preferably Grade 500E.

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REFERENCES