CCC 2018

Proceedings of the Creative Construction Conference (2018)
Edited by: Miroslaw J. Skibniewski & Miklos Hajdu
DOI 10.3311/CCC2018-078

Creative Construction Conference 2018, CCC 2018, 30 June - 3 July 2018, Ljubljana, Slovenia

Opportunities and challenges in adopting higher strength reinforcement bars in reinforced concrete structures

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Abstract

The improvement in technology has enabled the strength of reinforcement bars to be progressively higher and a few developed nations have explored and embraced such changes in their construction industries. The paper outlines the opportunities and challenges faced by the Singapore construction industry in using a higher strength reinforcement. While the Eurocodes, the nation's design code, allows GR600 steel to be used, attempts to use to that strength limit have begun but there are still issues to be overcome before a wide spread acceptance and adoption can take place. Information from pilot projects on the use of such reinforcement shows that the benefits outweights the drawbacks.

Keywords: Reinforced concrete; steel reinforcement; high strength; challenges; opportunities

1. Introduction

The desire for taller and more complex strucures has led to the need for stronger and better construction material. The strength of concrete and steel has progressively improved over the years to meet this demand. However, the increase in the strength in concrete and steel also has its drawbacks and safety concerns. Design codes in different parts of the world have been revised and updated to cater for the design challenges poised by these new and stronger material. However, there are also significant advantageous and opportunities in adopting these new stronger material.

2. Benefits of higher strength reinforcement bars

The role of steel reinforcement bars in reinforced concrete structures is well known and as by increasing the strength of the steel, the direct economic gain can be significant. For example, by having smaller beam sizes from stronger steel reinforcement can result in floor height or a reduction in column sizes can increase the net usable (also probably rentable) space.

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 DOI 10.3311/CCC2018-078

The use of higher strength steel bars can also lead to reduction in amount of steel used and this has many benefits which translate in better construction productivity;

- Less congestions of steel bars which helps in improving the placing and compaction of concrete, hence better quality of casting
- Less amount of work thus cost for the preparation of the steel cages e.g. less cutting, less tying and less transport and handling

With a requirement of a higher transfer length between the higher steel bar and concrete, there is a tendency or need to use couplers and end anchorage accesories instead of lapping. This leads to less congestion of steel bars which adds to the improvement in construction productivity.

The reduction in the amount of steel reinforcement also helps in the Green and Sustainability initiatives for the construction industry.

3. Trends in different countries

In the United States Grade 100 (fy = 689 MPa) and Grade 120 (827 MPa) have been widely available nowadays in most states. These two grades have been introduced in ASTM A1035, Standard Specification for Deformed and Plain, Low-Carbon, Chromium, Steel Bars for Concrete Reinforcement since 2004 [1]. ACI ITG-6R-10 Design Guide for the Use of ASTM A1035/A1035M Grade 100 Steel Bars for Structural Concrete [2], provides recommended design provisions by which the higher yield strength is used to increase member flexural and axial strength.

High strength of thread bar SAS 670/800 (fy = 670 MPa) has been produced since 1999 in Hammerau (Germany). The use of this high strength rebar is not limited in Germany but has been used in other countries such as the New World Trade Center in New York, USA or the LotteCenter in Seoul, Korea [3]. An evaluation of this material for use with ACI code in the United States can be found in the report from the International Code Council Evaluation Services, ESR-1163 [4].

In Japan, high strength rebar USD 685 (fy = 685 MPa) was first used in 1993 for a 45-storey condominium [5] and since then it has been used widely in high rise construction in the country.

In Korea the high strength rebar grades SD600 and SD700 have been added to Korean standard KS D 3504 and the design code in 2012 has allowed the yield strength of rebar to increase from 550 MPa to 600 MPa [6].Currently big steel manufacturers including Hyundai Steel, Dongkuk steel in Korea supply both SD600 and SD700 in accordance with Korean standard KS D 3504.

In some projects, the use of high strength steel in applications also surpass the code recommendation; using bar diamaters of up to 75 mm and percentage of steel of up to 18% [7]

4. Adoption in Singapore

The Building and Construction Authority in Singapore has adopted the Eurocodes as the building design codes in 2013. Prior to change, BS8110 or CP65, its local adaptation, was the design code for reinforced concrete works where the highest strength for concrete and steel reinforcement were Grade 60 and GR500 respectively. The adoption of the Eurocodes has extended the upper limits to Grade 105 and GR600 respectively. There are many challenges and opportunities resulting from this change:

4.1. Regulatory Framework

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The quality of steel reinforcement depends on technology used and quality control of manufacturers. Singapore, being a free market and steel bars can imported from different sources around the world. It is very important to have stringent specification and quality control for rebars used in the country. The regulations require the Qualified Person (QP) who is the engineer responsible for the project to carry out essential tests on the materials used in the building works. Such tests are required to be carried out in a laboratory accredited for those tests. The QP can specify either BS4449 [8] or SS560: 2016 [9] as the standard for steel reinforcement in conjunction with the Eurocodes.

Mill certificates are not to be taken as proof that quality of material is acceptable. The number and frequency of tests are to be specified by QP in approved plans and specification to ensure the quality of rebar delivered to site confirm to the required standards. The QP is required to report to the authority if there is failure of the tests and to recommend remedial works. Unlike the steel of G500 or lower, the contractor or supplier proposing the use a higher strength Grade 600 rebar shall pre-consult the authority for the use of such rebars in any project prior to the use.

SS560 is a Singapore standard and it was revised in July 2016 to include the higher strength GR600 steel reinforcing bars to facilitate the construction industry to adopt and use GR600 rebars more widely in the local high-rise building and other construction projects. To ensure product conformity to the requirement, SS560 has stipulated a third party product certification scheme for such evaluation called the "Factory Production Control" or FPC certification. This conformity evaluation includes verification of standard properties, evaluation of test results and continuous surveillance of factory production control and audit testing. Steel reinforcment from sources without FPC certfication must be subjected to the material verification and routine quality control tests to ensure conformity.

In SS560, there are 3 different ductility classes –Class A, B and C for both the GR500 and GR600 rebars. Other than the change in yield strength of 600MPa, other mechanical properties are exactly the same as GR500. To facilitate the use of couplers, a new surface geometry called 'Threaded Ribs' has been introduced.

As to the site and quality control for GR600 rebars, it is not uncommon to have different grades of rebars used on the same project. Therefore, it is important for QP and site supervisors to have an effective site control system to differentiate and identify the right grade and ductility class. SS560 stipulates each reinforcing steel must have identification marks to identify the steel grade.

4.2. Key Challenges

- SS560 is only a product standard for rebars and but standard for other components in the rebar systems e.g. couplers, lock nuts or anchor plates are also to be specified.
- There are some concerns in the use of high strength steel reinforcement [10] e.g.
  - inability to fully utilise the potential strength of the high grade
  - may be more brittle
  - more cracking
  - more deflection
  - less effective as shear reinforcment
- Even though the Eurocodes permits the use of steel up to GR600, there is insufficient information or guidance or advice on its use. Hence, there is a need to have a design guide for the industry because the use of the higher strength steel is still new and the users are not familiar.
- Even though the SS560 has a FTC scheme to ensure the right material is used, the Singapore market is relatively small and many overseas mills refuse to meet such requirement. That limits the number of approved source of supply

4.3. Accesories e.g. Couplers

For almost 100 years, construction practices in the building of concrete structures have focused on the use of steel reinforcement to transfer tension and shear forces. The use of laps can be time consuming in terms of design and installation and can lead to greater congestion within the concrete because of the increased amount of rebar used. Reinforcing bar couplers available in the market have come across with a solution for this complexity as it provides a greater ease in design and construction of reinforced concrete and reduce the amount of reinforcement required. The strength of a mechanical splice is independent of the concrete in which it is located and will retain its strength despite loss of cover as a result of impact damage or seismic event. Force transfer mechanism of the coupler can be in different way: 100% mechanical, 100% chemical or a combination of mechnical and chemical. Different types of couplers are shown in Figure 1:

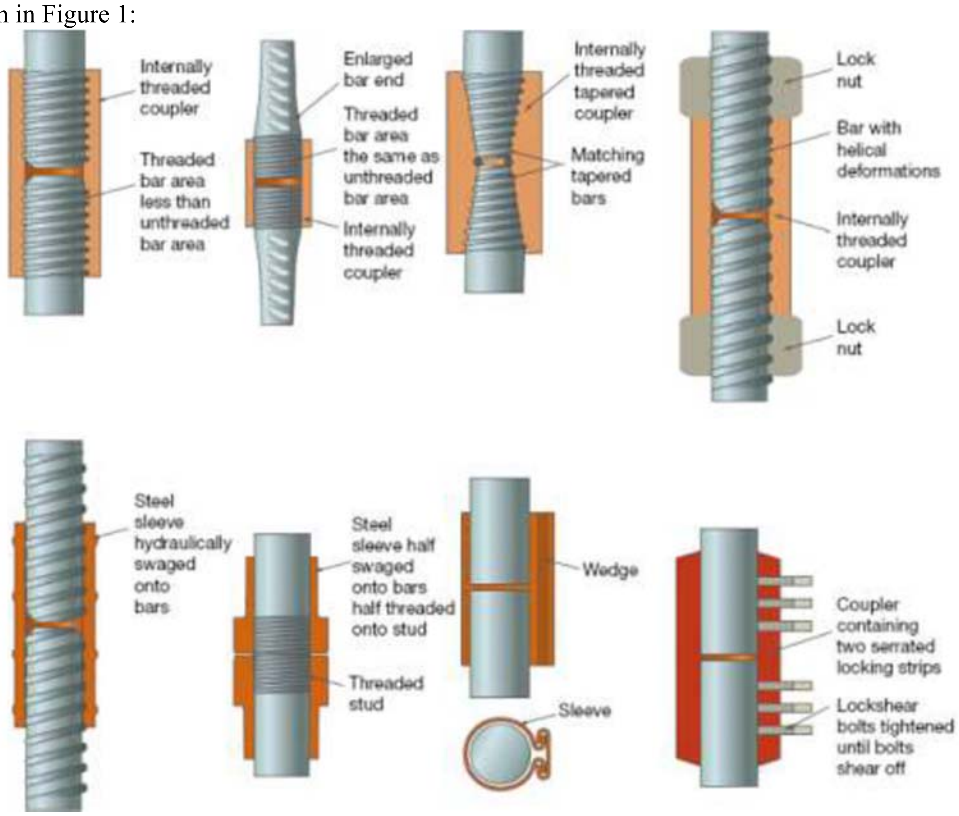

Figure 1 Different types of couplers

Currently, there is no stipulated standard in the regualtions on the use of couplers. However, the ISO 15835-1: 2009 & ISO 15835-2: 2009 [11] are suitable ones to be adopted. This standard has a similar ”FPV” scheme for product conformity scheme but this would face the same challenges as the SS560 because of the size of the Singapore market. This two parts of the 2009 ISO are currently in the final stage of revision and will be released soon in three parts.

4.4. Pilot cases

Two projects explored to use the GR600 steel rebars as an alternative to the GR460 steel rebars. The results obtained are shown below :

- LTA Thomson East Coast Line T211 PJ [12]

In the project, GR600 TTK's threaded rebar and TTK's threaded rebar Joint System was proposed as an alternative design for parts of secant bored piles (SBP) walls in Thomson East Coast Line- Contract T211Project. • In the original design, one number of SBP comprised of 3 or 4 types of steel cage. Every rebar cage has different rebar arrangement depending on the design force. In the Alternative Design using higher strength steel with compatible coupler joint System, the reinforcement bar amount are reduced and thus its arrangement is revised to be uniform thoroughly all length of pile. As a result, the number of cages per pile is decreased from 3/4 cages to 2 cages. Figure 2 and 3 shows rebar arrangement of the original design using GR460 and alternative design using GR600 steel.

DOI 10.3311/CCC2018-078

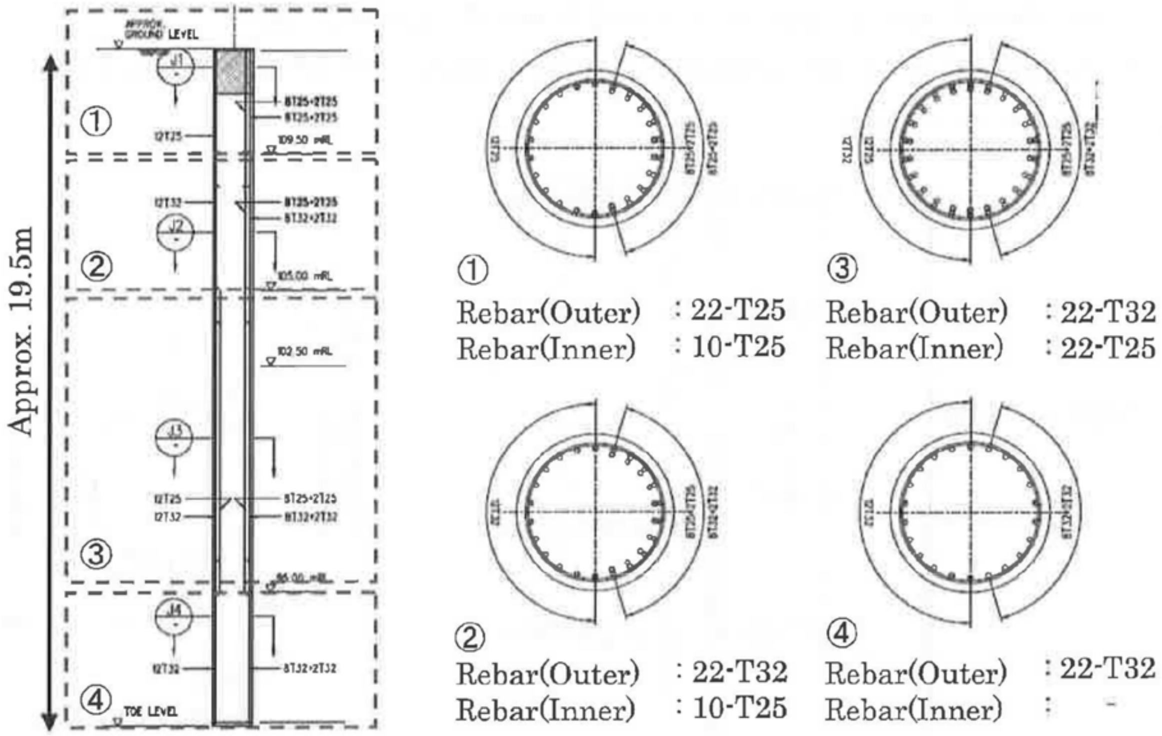

Figure-2. Typical rebar arrangement of original design(SBP-34C)

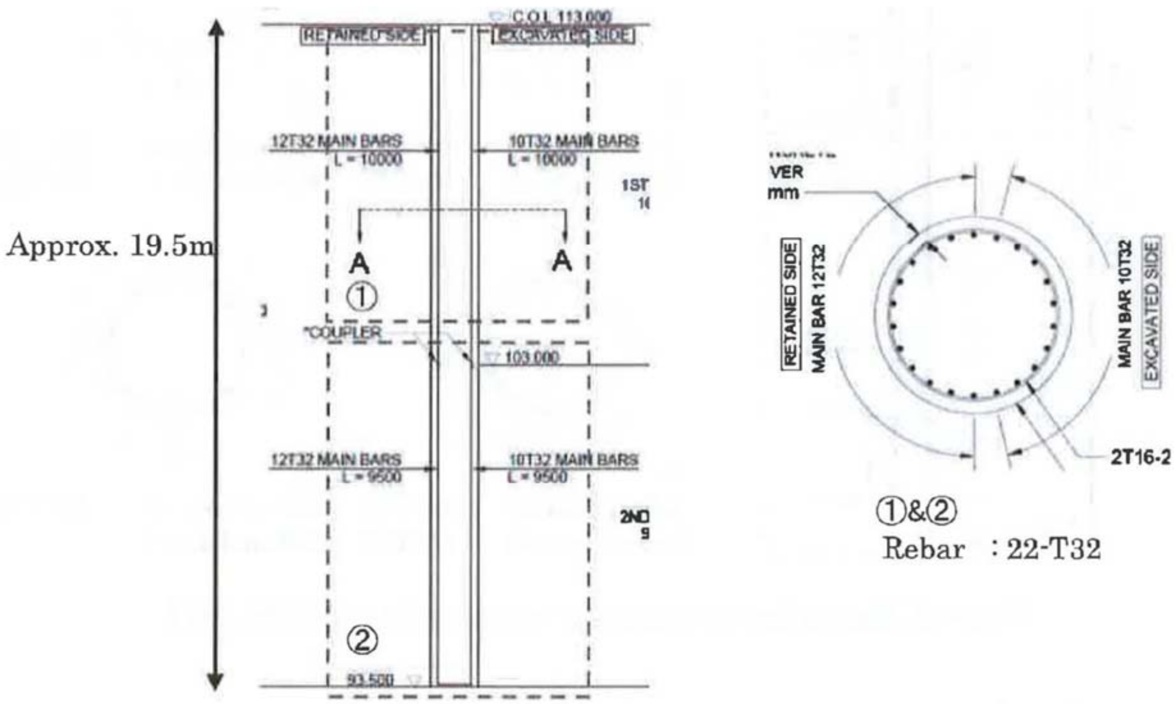

Figure-3 Typical rebar arrangement of the Alternative design (SBP-34C)

The benefits of adopting the alternative design using high grade reinforcement and compatible coupler system are described as follows:

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- Reduction of Rebar - Total reduction is 22.4% which consists of main rebar reduction of 11.6% and the overlapping bar saving of 10.7% by replacing with the coupler joint.
- Saving of Construction Time and Man-Hour - With the reduction in the rebar amount, not only the time spend for rebar fixing work on site is lesser, the prefabrication of rebar (cut, bend and caging) are also improved.
  - When the number of cages was reduced from the original 4cages/pile to 2cages/pile, the construction time was reduced from 200 to 100min/pile, thus 100mins (50%) was saved.
  - When the number of cages was reduced from the original 3cages/pile to 2cages/pile, the construction time was reduced from 140 to 100min/pile, thus 40mins (29%) was saved.
- Quality Improvement - With the reduction of the main rebar amount, the rebar spacing was increased and the congestion of bars was improved thereby also improving the concrete flow to the outside of the rebar cage during the casting and could therefore lead to better quality of the bored pile concrete. The less congestion of rebar arrangement will also help to ease of installation of anchor bars for the connection with RC slab structures. This also improved the productivity in both of pre-installed and post drilled anchor bars.
- Safety Improvement - Since the stiffness of the coupler is high enough to support the connecting prefabricated cage rigidly. Once the rebar cages are fixed by the couplers, there was no concern of falling-off/slippage of them due to failure of joint even before the joint grouting works.

Table 1 shows a sumary of the comparison between the original and alternative design

<table>
<tr><td>Items</td><td>The Original Design
(Gr.460 with lap Joint)</td><td>The Alternative Design
(Gr.600 with Coupler)</td><td>Reduction
%</td></tr>
<tr><td>Rebar Q'ty/Fabrication</td><td>80.65 ton</td><td>62.62 ton</td><td>22%</td></tr>
<tr><td>Construction time
4 cages in original design</td><td>200 min /pile
12.0 man-hour / pile</td><td rowspan="2">100 min /pile
6.0 man-hour / pile</td><td>50%</td></tr>
<tr><td>Construction time
3 cages in original design</td><td>140 min /pile
8.3 man-hour / pile</td><td>29%</td></tr>
<tr><td>Quality</td><td>NA</td><td>Concrete flow is improved due
to less congestion of bars</td><td></td></tr>
<tr><td>Safety</td><td>NA</td><td>Prevent from joint slippage
during cage installation</td><td></td></tr>
</table>

- Tiong Seng Hub – a 9-storey General Industrial Factory Building

GR600 steel reinforcement was used for the columns, beams, slab and walls from 1st storey to the roof. From GR500 to G600 steel, there would be a 20% in steel amount from the higher strength but the average steel savings of about 15% was achieved (12% for the columns and 18%-20% for the beams and slabs). The unit cost of the GR600 steel was 20% higher than that of GR500. However, there is an improvement in the productivity and the manpower resulted in a saving of about 20%.

5. Conclusion

Higher strength steel reinforcement especially with high strength concrete allows stronger structures. The benefit of the saving in steel amount from the higher strength steel is currently offset by the higher unit cost. However, the lesser steel usage will lead to less manpower and transportation cost which is an important consideration in Singapore where construction productivity is one of the key concerns. In addition, there are also indirect benefits such as smaller members which in turn lead to more useable spaces. A reduction in the number of steel rebars and use of couplers also produce better quality of construction because of the elimination or reduction of congestion that prevents proper placing and compaction of concrete.

In spite of the benefits, the wide spread adoption of this higher strength rebars currently still face many challenges. The lack of familiarity in design using higher strength is hindering the use. A design guide will certainly be helpful in providing a better understanding of the issues such as gains as well as the limitations in pushing the boundaries. The need to ensure product conformity such as the FPC scheme can face practical problems for a relatively small small construction industry, especially so when the demand of the product at the early phase is still low. But this will improve when the demand increases. With the encouragement from the Authority, particularly on the productivity standpoint and when clients are more aware and receptive to this higher strength rebars, the usage is expected to popular with the normal strength counterparts.

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