Study on Combination of Stainless Steel Reinforcement and Lightweight Concrete in Structural Members

Concrete Laboratory
Adrian Leonardo Ferrino Patino
Professor: Takumi Shimomura

1. Introduction and objective

This study intends to evaluate the effectiveness of combining stainless steel and lightweight concrete in RC structural members. The expected merits of using this combination of materials are the high resistance to corrosion of stainless steel which permits to have a smaller concrete cover thickness and reduce the cross-section size of the member, and the low density of lightweight concrete which can be approximately 30% lighter than normal concrete and can reduce dead-loads, which decreases the size and reinforcement of structural members. The objective of this research is to observe and analyze with an experimental study and case study if the mechanical behavior of lightweight concrete and stainless steel is satisfactory and can be applied to structural members. Also, verify if the application of lightweight concrete and stainless steel in the design of structural members can produce reductions in the size, weight and amount of reinforcement.

2. Research method

The research method of this study consists in the evaluation of 4 combinations of materials which are normal concrete + carbon steel (N+C), normal concrete + stainless steel (N+S), lightweight concrete + carbon steel (L+C), lightweight concrete + stainless steel (L+S). In this case, L+S is the main combination to evaluate. However, the other 3 combinations will serve as a comparison group to analyze differences in the obtained results. This research consists in performing to these 4 combinations of materials an experimental study to evaluate the mechanical performance and corrosion resistance, and a case study to evaluate its use in an example of a bridge design.

3. Case study

The case study consists in a comparison of 4 vehicular bridge designs in corrosive environments, using the 4 combinations of materials stated before following the "AASHTO LRFD Specifications". The objective is to evaluate L+S which is expected to reduce the size of the structure, the reinforcement and weight.

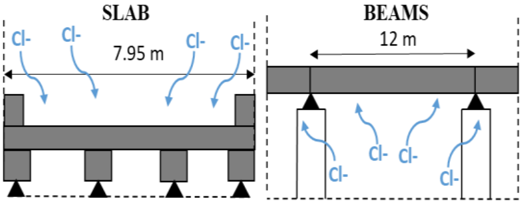

Figure 1: view of the dimensions of the bridge.

3.1. Results and discussion

After the analysis of loads and computation of the dimensions, a design section of each material combination was obtained. Then, estimations of the total weight, amount of reinforcement and volume of concrete were performed for each design to observe differences in these values. In ***Figure 2,*** it can be observed a table with the volume of concrete needed for each material combination and when using lightweight concrete and stainless steel (L+S), almost the lowest value of the necessary volume of concrete can be obtained which is 37.54 m^3. If this value is compared with the 39.69 m^3 of concrete volume required by N+C, it can be observed that L+S saves 2.15 m^3 of concrete which is an important saving if the bridge have several sections to build.

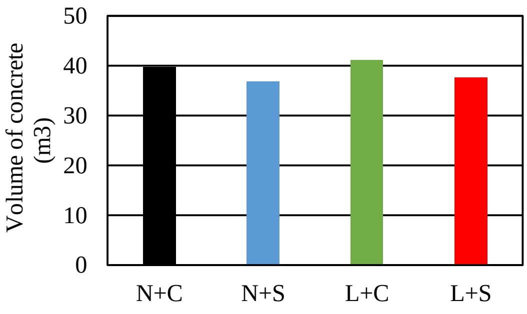

Figure 2: concrete volume of bridges.

In ***Figure 3***, it can be observed that the L+S combination has a very low total weight equal to 62.67 Ton when it is compared with the total weight equal to 95.24 Ton of N+C. It was verified that L+S could reduce 30% the total weight when it is compared to N+C.

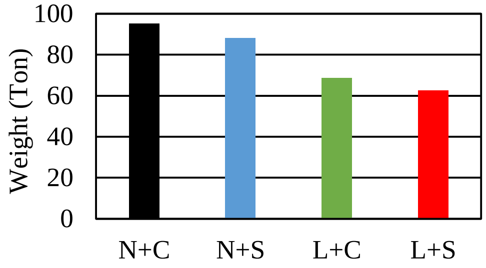

Figure 3: total weight of bridges.

In ***Figure 4,*** it can be observed that L+S needs 95223 mm^2 of steel area, while N+C requires 115504 mm^2. With this it was also verified that L+S decreased the amount of reinforcement in the structure if it is compared with the N+C combination.

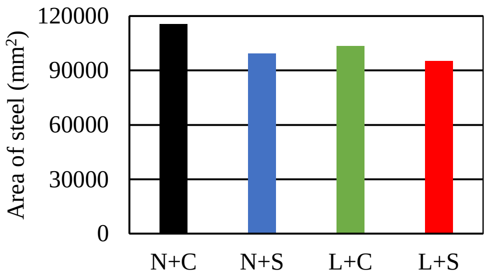

Figure 4: steel area of bridges

4. Experimental study

The experimental study consists in a loading test to evaluate the mechanical performance of the specimens to confirm if L+S can offer a satisfactory mechanical behavior. Then, since the diffusivity of chlorides in lightweight concrete must be studied, the corrosion behavior of the reinforcing steel mainly inside lightweight will be evaluated with an accelerated corrosion test. Regarding the corrosion test, it is currently being done and results haven't been obtained.

4.1. Specimens and loading test

The 4 specimens are reinforced concrete beams based on the Bench Mark Test by JSCE 311 Committee [2]. The specimens consist in a main steel bar D13 with 2 strain gauges to measure its strain, stirrups D6(SD345) or D5(SUS304) every 100 mm as shown in ***Figure 5***.

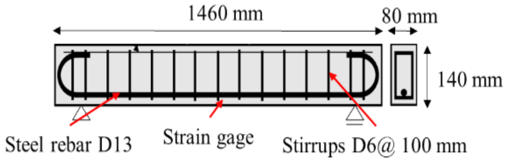

Figure 5: characteristics of specimens.

Figure 6 shows the setting for the loading test which consists in a load-cell, hydraulic jack, the specimen simply supported, deflectometers and 3 strain gauges placed on each face of the specimen to measure its strain.

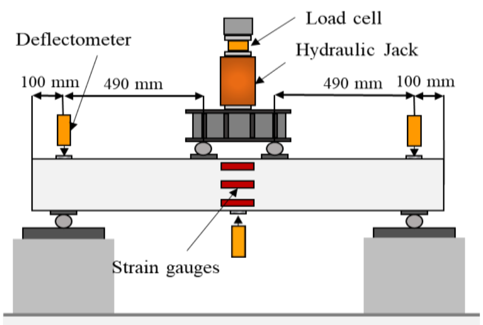

Figure 6: setting of loading test.

Table 1 shows the properties of the concrete obtained with a compression test to 3 cylindrical specimens of each concrete type. The objective of the loading test is to measure the load, strain on concrete and steel, deflections, and crack development in all 4 specimens to target the differences in the mechanical behavior.

	Average compressive strength (MPa)	Modulus of elasticity (MPa)	Density (kg/m^3)
Normal concrete	54.6	38451	2280
Lightweight concrete	35	20134	1580

Table 1: concrete properties.

4.2 Results and discussion

The strains in the main steel bar of the specimens can be observed in ***Figure** 7*. According to the table it is observed that the shape of the slopes of the lines of all the specimens depends mainly in the type of the steel. The specimens with stainless steel had less strains than the carbon steel at initial stages during the same loads, and a bigger ultimate strength than the specimens with carbon steel. Also, it can be observed that specimens of lightweight concrete presented bigger strains than specimens of normal concrete at similar loads. However, this differences were not drastic and may be due to the variation of 19.4 MPa in the compressive strength of lightweight concrete and normal concrete.

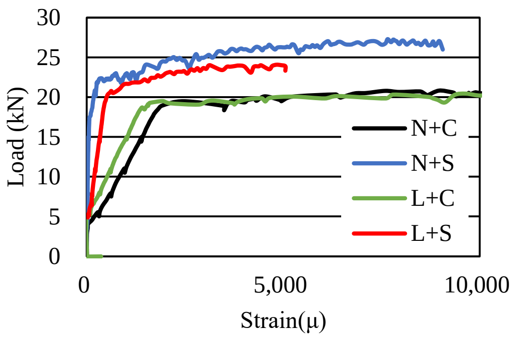

Figure 7: strains in the steel bar of specimens.

Regarding the deflections of the specimens, the ***Figure 8*** shows the deflection development of the specimens during the loading test. It was observed that specimens using lightweight concrete presented very similar deflection values under similar loads like normal concrete specimens. There were some differences in the maximum deflection value, since lightweight concrete specimens had less ductility and deflected less than normal concrete specimens at ultimate load. However, this difference was not drastic and may be due to the variation in the compressive strengths of the concrete mixes showed in the ***Table 1.*** Regarding the crack development, according to the sketches of cracks in ***Figure 9***, it can be observed that crack development was similar since the spacing and deepness of cracks were equivalent between combinations of lightweight concrete and normal concrete during the loading test.

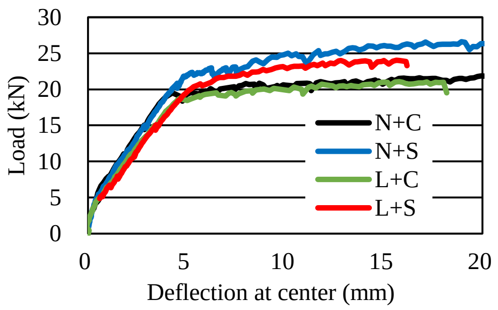

Figure 8: deflection development of specimens.

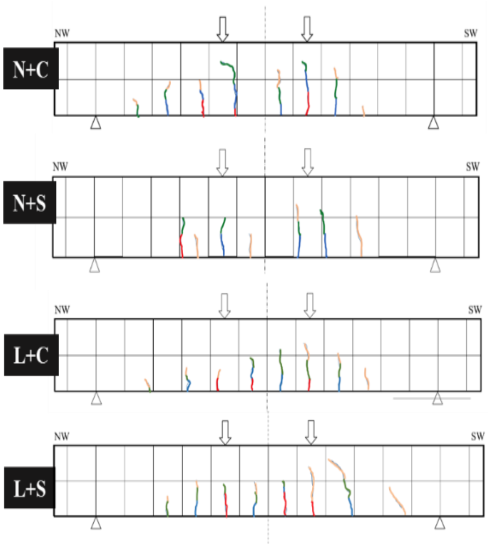

Figure 9: crack sketches of specimens.

4.3 Expected results for corrosion test

Since lightweight concrete is a more porous material it is expected that it presents a faster ingress of chlorides than normal concrete. However, since the experiment is currently being done results haven't been obtained.

4.4 Conclusion of obtained results

Case study: in the case study it could be observed that when using lightweight concrete and stainless steel in a vehicular bridge under same loading and support conditions, same dimensions and the same environmental conditions (marine environment), there was a 30% reduction of the total weight and a decrease in steel reinforcement. In addition, this reduction of weight may have a positive effect to reduce the dimensions and necessary reinforcement of other structural members that will carry these loads. Also, since stainless steel is used it can be expected to have a longer service life of the structure and less maintenance and repair frequency [1].

Experimental study: it could be observed that L+S showed a very similar cracking load like N+C. Some differences were obtained in the deflection development, however they were minimum and may be due to the differences of the compressive strength between the concrete mixes. Regarding the crack development, if the sketches are observed, cracks had very similar spacing and deepness which may indicate that in this experimental study lightweight concrete and normal concrete developed cracks on similar ways during the loading stage.

5. References

[1] ACI Committee 222, 2001, *Protection of Metals in Concrete Against Corrosion,* American Concrete Institute.

[2] ACI Committee 213, 2003, *Guide for Structural Lightweight-Aggregate Concrete,* American Concrete Institute.