CHAPTER 5

SUMMARY, CONCLUSIONS and CLOSING STATEMETS

5.1. Summary

The purpose of this research project was to derive a relatively simple yet acceptably accurate model to predict the strength of composite floor shear connections featuring the ELCO Grade 8 standoff screws.

The strength prediction model was derived based on the results of 254 push-out tests performed at Virginia Tech. The results from 6 available full-scale short-span joist tests that featured standoff screws as shear connectors were not used to evaluate the performance of the strength prediction model.

This study was based on the realization that the failures of shear connection in composite floors occur in three different modes: screw shear, concrete rib failure, and screw pullout. Each of the failures was analyzed separately, and the final strength prediction model represents a synthesis of those analyses.

In addition to deriving the strength prediction model, a reliability study aimed at deriving a strength reduction factor for the ELCO Grade 8 standoff screws was also conducted. It was shown that the derived strength reduction factor should ideally be applied to the strength of the standoff screw and that this reduced strength should be used in the calculation of composite member moment capacity. The proposed ELCO Grade 8 standoff screw strength prediction model is shown below as Equation 4.4.

When the rib is perpendicular to the joist:

$$\Phi R_n = \Phi \min \left| \begin{array}{l} 36.71(t_{tc})^{1.61}\left(\dfrac{H_s}{h_r}\right)^{0.75}\left(1 - 0.15w_{r1}^{2} + 0.98w_{r1}\right) \\ \dfrac{0.18(\ln f'_c)L_{sp}w_{r1}^{0.13}}{N^{0.74}} \leq \dfrac{0.15A_{sc}F_{ut}}{t_{tc}^{0.61}} \end{array} \right| \qquad (4.4a)$$

When the rib is parallel to the joist:

$$\Phi R_n = 0.45\, A_{sc} F_{ut} \qquad (4.4b)$$

where:

Φ = strength reduction factor = 0.85

R_n = shear strength per screw, kips

t_{tc} = top chord thickness, in.

H_s = screw height, in.

h_r = rib height, in.

w_{r1} = bottom rib width, in.

f'_c = concrete compressive strength, psi

L_{sp} = length of the shear plane, in.

$$L_{sp} = 2\sqrt{\left(\frac{w_{r2} - l_s}{2}\right)^2 + (H_s - h_r)^2} + l_s$$

w_{r2} = top rib width, in.

N = number of screws per rib $\leq$ 12

A_{sc} = nominal cross-sectional area of the screw, in.^{2}

F_{ut} = screw tensile strength stress, ksi

l_s = vertical distance between screws in a rib, in.

In performing the abovementioned reliability study, several additional issues were identified. Their nature and significance exceed the scope of this study, and subsequent studied may be required to address them. These issues are further described in the section 5.4.

5.2. Conclusions

Standoff screws appear to be a reliable alternative to welded shear studs in light-weight composite floor joists. Their overall ductility, relatively simple installation, and the elimination of welding are major advantages. A relatively high number of screws required in larger joists and a lack of ductile behavior when used in joists with thicker top chords are the most prominent disadvantages.

Using the ultimate strength of the screws versus using their strength at certain slip values (i.e., the slip of 0.20 in.) was shown to be justified and did not have adverse effects on serviceability.

The derived strength prediction model offers a reliable and relatively simple way to evaluate the strength of a lightweight joist composite section with standoff screws.

Longitudinal rib splitting, the occurrence of which is not characteristic for full-scale specimens, was happening routinely in push-out specimens that either contained a relatively large total number of screws per specimen, or were not sufficiently reinforced against rib splitting.

The effect of top chord angle yield strength on the strength of shear connection failing by screw pullout could not be fully realized from the available data due to the small range in the angle yield strengths.

ELCO Grade 8 standoff screws do not exhibit a satisfactory level of ductility when used in joists with relatively thick top chords. The result of CSJ-13 indicates that no redistribution of horizontal shear force occurs. Screws closer to the supports therefore fail first. At the same time, screws closer to the mid-span carry significantly less load, or no load whatsoever, at the time of failure of the first shear connectors.

The results of this study suggest the need for a different design procedure for composite joists than for composite beams in terms of how the strength reduction factor is applied. It would appear that the moment capacity of composite joists is directly proportional to the strength of the shear connector used, and thus the statistical characteristics of the strength of the shear connector have a direct effect on the strength of the composite section itself. The situation is completely different with composite beams; their moment capacities are not directly proportional to the strength of the shear connectors used. Also, statistical characteristics of the shear connectors affect the moment capacity of a composite beam differently at different percentages of composite action. These differences result from neglecting the contribution of the top chord to the moment capacity of composite joists. The resulting approach for composite joists would be to apply a separate strength reduction factor to the strength of the shear connector, and to then use that reduced strength in the calculation of the composite joist moment capacity and corresponding reliability studies aimed at finding a new strength reduction factor for the moment capacity of composite joists.

5.3. Limitations

There are a few limitations to the derived strength prediction model and the use of standoff screws in general. Most of them could be eliminated by subsequent research. They are as follows:

- The top chord thickness shall be in the range of 0.109 in. to 0.250 in. The lower limit is the thinnest tested thickness and the upper limit is governed by both the self-tapping characteristics of the screw and ductility.
- The yield strength of the top chord angle shall nominally be 50 ksi. At this point, it is unknown, how a significantly lower or higher top chord angle yield strength would affect the strength of shear connection.
- The number of screws per rib shall in no instance exceed 12, as that is the highest number of screws per rib experimentally evaluated. Most of the time this number will be governed by practical considerations as the space available for the installation of screws in narrower ribs is fairly limited.

5.4. Future Research Suggestions

Several additional issues should be resolved to be able to fully predict the behavior of standoff screws. They are listed as follows:

- <u>The effect of top chord yield strength on the strength of standoff screw shear connection</u>. This could be found by conducting several push-out test series featuring angle thicknesses between 0.109 and 0.138 in. and top chord yield strengths significantly lower or higher than 50 ksi.
- <u>The strength reduction factor for the moment capacity of composite joist</u>. This topic applies not just to standoff screws, but to all shear connectors. A research project on this topic would ideally include full-scale short-span composite joist tests that would have their shear connection strength designed using the strength prediction model and corresponding strength reduction factor derived in this study. Based on the results of these full-scale tests, a separate strength reduction factor would be derived for the composite joist moment capacity.

- Standoff screw ductility in thick top chords. An investigation of horizontal shear load distribution among screws in top chords greater than 0.200 in. should be conducted to determine the influence of this parameter on the flexural response of composite joists.
- Longitudinal rib splitting. Based on occurrences of longitudinal rib splitting, any subsequent push-out tests should contain the least total number of screws per specimen possible (ideally less than 14) to prevent this inapplicable mode of failure.