Decreasing Embodied Greenhouse Gas Emissions in One-Way Slabs Through Concrete Strength Reduction and Thickness Optimization

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Summary:

Concrete slab thickness is a key driver of embodied GHG emissions in modern buildings. This is in part driven by a widely-used method to select slab thickness which is based on the span-to-depth ratio and usually provides conservative slab thickness values. Optimizing slab thickness through an iterative method by checking deflection limits is already an available (if inconsitently used) option in structural design codes. Common norms specifying concrete strength, similarly regularly call for 35 MPa and above, rather than optimizing for required bending and shear capacity. Lower concrete strengths generally have lower embodied carbon, and the minimum allowable concrete strength by the Canadian code for buildings (CSA A23.3:24) is 20 MPa.

In this research, we start with a parametric analysis to quantify the potential embodied GHG savings associated with reductions in slab thickness and concrete strength that are currently allowable within code. This analysis consisted of the design of 80 slab configurations to represent a wide range of conditions in typical buildings. Slabs were designed first with an initial thickness determined by the span-to-depth ratio and then with an optimized thickness to calculate the reduction in GHG emissions – accounting for embodied GHG from both concrete and reinforcing steel. Results show that reducing slab thickness and concrete strength were associated with meaningful GHG savings, and that long-term deflection control was the governing factor for slab thickness.

Following these findings, an experimental program was carried out to verify if code provisions are accurately predicting strength and serviceability when applied to thin and low-strength concrete slabs (important to confirm before designing and building thinner, weaker slabs). A set of six one-way slabs with three different thickness and reinforcement ratios were tested under four-point bending until failure. Results confirm the behaviour of the tested thin 20 MPa slabs followed code expectations. The findings indicate that thin and low-strength concrete slabs (already allowed within code) can be used to lower the embodied GHG of concrete buildings.

Key findings:

- **Reducing thickness and concrete strength yielded large GHG savings** — Decreasing slab thickness by optimizing for strength and deflection control was associated with up to 33% of embodied GHG savings. Thus, a slab that might currently be designed as 195 mm thick could also work for strength and deflection if it was only 135 mm thick with a 25% increase in the amount of flexural reinforcement. A reduction of 18% to 27% in GHG emissions was calculated when decreasing concrete strength from 35 MPa to 20 MPa. Combining both strategies yielded GHG savings of 24% to 46%. All evaluated slabs were designed to meet CSA A23.3:24and NBCC requirements.

- **Deflection control was the governing factor for slab thickness** —The long-term deflection limit, which is a serviceability requirement rather than a safety concern, was the limiting factor for further reductions in slab thickness in all cases.
- **Code predictions were accurate for thin and low-strength concrete slabs** — Code provisions for immediate deflections showed a high degree of agreement with experimental values, especially in the range of service loads. Other slab parameters such as crack control, flexural and shear strength were also accurately predicted by the code.

Fig. 1—Short-term flexural test - NR3 [h = 300 mm].

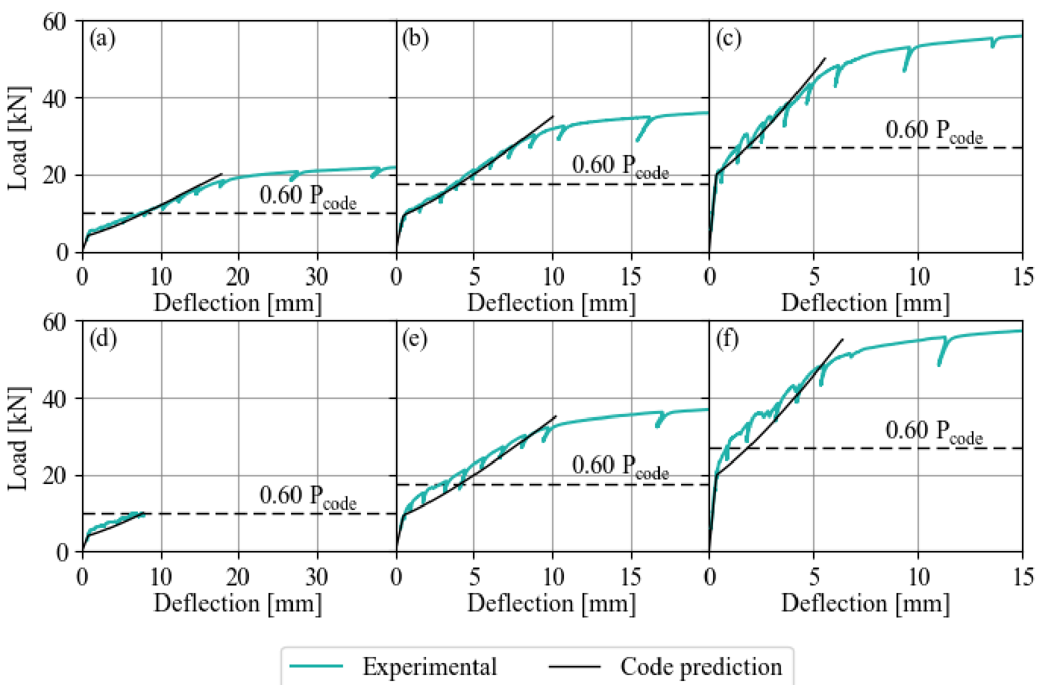

Fig. 2— Experimental Load-deflection curves and predicted values by CSA A23.3-24 for specimen (a) NR1, (b) NR2, (c) NR3, (d) LT4, (e) NR5, (f) NR6.