Combined in-plane and out-of-plane shear in concrete bridges

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1. Background

The number of existing concrete bridges, whose design lifetime is soon to be exceeded or where a higher capacity to carry heavier traffic is desired, are increasing rapidly.
When assessing whether the bridges need to be **strengthened, replaced, or can be kept in service**, it is important to have accurate and well-documented models. As the load-carrying capacity of many of these bridges is **governed by the shear capacity**, the need for accurate shear models is especially important.

When a bridge is loaded, e.g. by traffic loading or self weight, so-called shear forces appears as both in-plane and out-of-plane shear. The two types of shear is illustrated in Fig. 1.

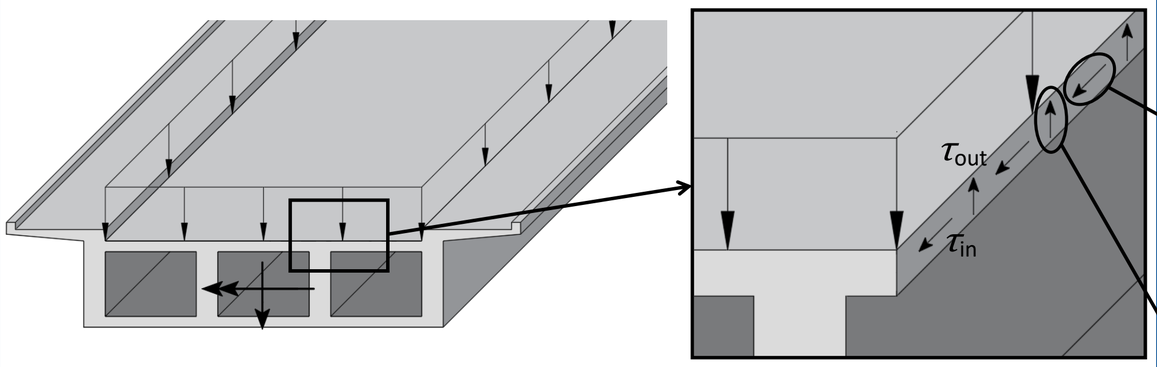

Fig. 1: Illustration of a box girder bridge subjected to distributed vertical loading (left) and the acting in-plane shear (τ_{in}) and out-of-plane shear (τ_{out}) in a cross-section of the top slab (right).

Both the in-plane shear (τ_{in}) and out-of-plane shear (τ_{out}) have been investigated thoroughly, as shown in Fig. 2 and 3, where the known failure mechanism for each type of shear is illustrated.

The combination of the two types of shear, however, has received very little research attention. **Only one experimental study exists** in the literature and here the representativeness of the experiments can be questioned due to the employed experimental setup. The failure mechanism of the combination is therefore still unknown in the literature

As a consequence of the lack of research attention, the approaches in **current design guidelines are unsophisticated without foundation in research or experimental evidence**, and hence it is unknown if the guidelines yield conservative or unsafe results.
A conservative result leads to bridges being unnecessarily replaced or strengthened resulting in significant CO_2 emissions and excessive usage of materials. An unsafe result leads to higher risks of collapse.

2. Aim of project

The aim of the project is to establish **a shear model which takes the combination of the two types of shear into account** and calculates an accurate shear capacity.

- The model should be analytically derived with basis in actual failure mechanisms to ensure that the model can be widely used in practice, and be used outside its empirical foundation.
- Such an analytical model will make it possible to establish an effective strengthening strategy for structures subjected to both types of shear.

3. Research questions

How can combined in-plane and out-of-plane shear be tested?

⇒ How can the shear forces be applied in a controlled manner?
⇒ How can the distribution of in-plane and out-of-plane shear be measured while testing?
⇒ How can the failure mechanism be measured and quantified?

How does in-plane shear affect the out-of-plane shear capacity?

⇒ How do the relevant design parameters influence the combined in -plane and out-of-plane shear capacity?
⇒ What are the governing failure mechanisms?

How can the established shear model be used to derive an efficient strengthening strategy?

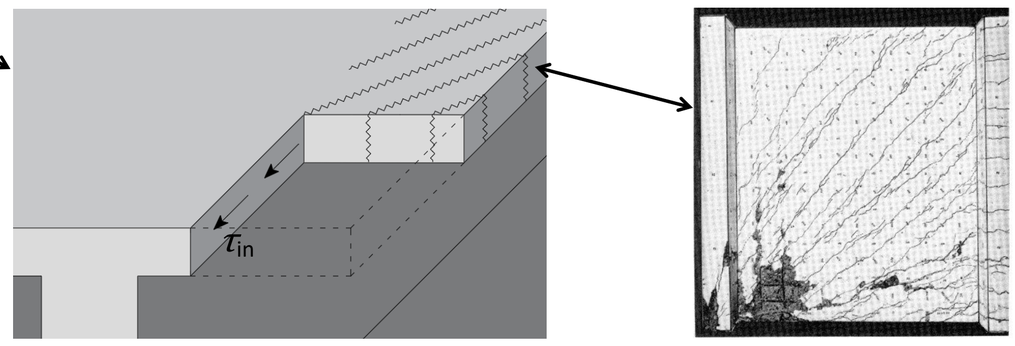

*Fig. 2: **Failure mechanism** of **in-plane shear** as illustration (left) and experiment (right).*

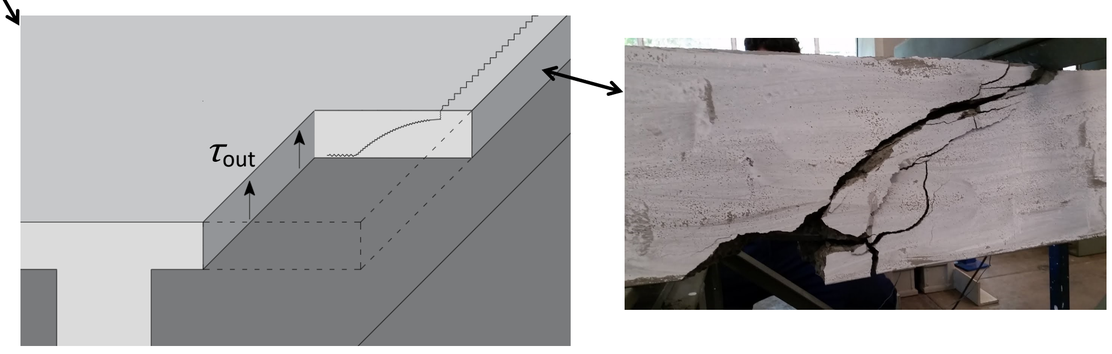

*Fig. 3: **Failure mechanism** of **out-of-plane shear** as illustration (left) and experiment (right).*

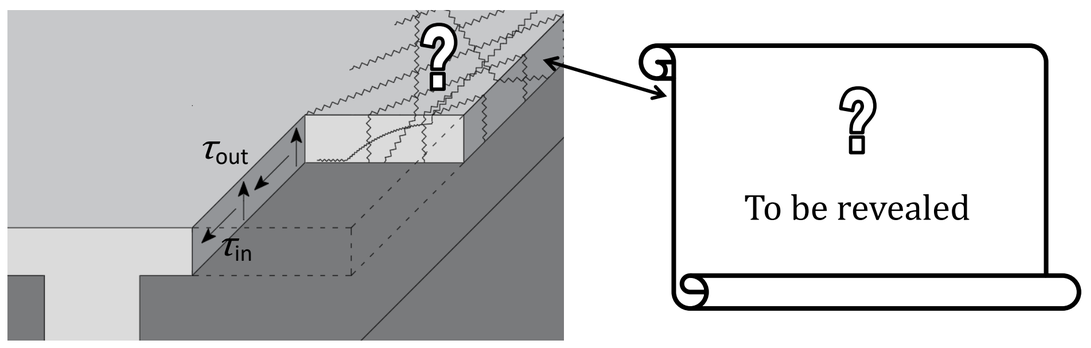

*Fig. 4: **Failure mechanism** of **combined** in-plane and out-of-plane is unknown.*

4. Method

The research questions are answered by:

- Study of available literature for in-plane and out-of-plane shear and the respective shear transfer mechanisms.
- Establishing a representative experimental programme.
- Developing an analytical model for combined shear.
- Development of an efficient strengthening strategy on the basis of the developed analytical model.

This project is financially supported by
Innovation Fund Denmark and COWIfonden