Summary

The design of reinforced and prestressed concrete girders is usually performed so as to avoid any non ductile failure mode. Amongst these failure modes, one of the most undesirable occurs by crushing of concrete in the web. To avoid this brittle type of failure, it is of paramount importance to know precisely the effective compressive strength of concrete in the web.
It is reduced by cracking (transverse strains), which is due to the shear deformations. In the presence of post-tensioning cables in the web, cracks may form along the cables inside the web, which also weakens the concrete of the web.

Numerous bridges have been built in Switzerland by using profiled girders with thin webs containing only a minimal amount of stirrups but large post-tensioning ducts, which occupy a considerable part of the web width. Both phenomena mentioned above play a role for these bridges, especially for more brittle high performance concrete.
The two phenomena are only partly understood. A sound physical model for the shear behaviour as well as a failure criterion are necessary to achieve a uniform safety level for new structures and to evaluate the strength of existing structures.

Large-scale laboratory tests on prestressed concrete girders have been conducted in order to improve understanding and to investigate both phenomena in detail. Web crushing along the post-tensioning cables was the mode of failure of all girders. In addition, laboratory tests have been conducted on prismatic specimens to investigate the effect of the presence of a post-tensioning cable in an isolated manner.

A physical model has been developed for the shear behaviour of reinforced and prestressed concrete girders. The variation of loading, stresses and strains along the girder axis is taken into account. The shear capacity of the compression flange is considered on the basis of equilibrium and compatibility. The load increase in the post-tensioning cables is calculated with a bond condition.

A physical failure criterion has been developed for the effect of the presence of a post-tensioning cable. The failure load of the conducted prism tests and a large number available in the literature has been estimated with a good precision for various post-tensioning duct types and concrete cylinder strengths. Based on physical considerations a failure criterion has been developped that takes into account the effect of transverse strains.
Both effects are more pronounced for a higher cylinder strength.

With the developed physical model and the failure criteria, the failure load of a large number of reinforced and prestressed concrete girders (laboratory and from the literature) has been estimated with good precision. The interaction of the effects of the presence of a post-tensioning cable and of transverse strains has been taken into account for the development of a combined failure criterion. Its format is compatible with the current design codes.

Keywords: Reinforced concrete, prestressed concrete, shear, test, large scale, shear strength, web, crack, web crushing, prestressing, post-tensioning duct, stress fields, compatibility, bond, physical model, failure criterion.