# Discharge buckling assessment of slender silos considering different forms of Eurocode patch load

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**Abstract**
Thin-walled silos are one of the major storage structures in most of industrial and agricultural sectors. Due to small wall thickness of steel silos, they are susceptible to buckling failure. Discharge process of ensiled materials typically result in some sources of asymmetry in the pressures imposed on silos walls. EN 1991-4 cover this issue by introducing patch load concept as an additional load that should be considered in discharge design of silos. This study investigates the buckling capacity of an example slender silo by taking into account two different forms of patch load proposed in the Eurocode.
**Keywords: Steel slender silos, Discharge patch load, Buckling, Eurocode**

## 1. INTRODUCTION

Steel silos are key structures for storing granular materials in many industries and agricultural sectors. These storages are usually composed from isotropic rolled sheets or corrugated ones with small thickness. They may also be stiffened by vertical or ring stiffeners in the outer or inner skin of the shell walls. Due to small wall thickness, buckling is a probable failure mode in these structures. Steel silos are usually constructed in form of stepwise variable wall thickness as the stress resultants progressively increase toward the base. This makes several locations susceptible to buckling along the silo's height and where the shell thickness varies.
Although there are several actions to be considered in silos design, such as, wind action [1–3], seismic action [4] and filling and discharge loads [5–8], the most common and frequent load during lifetime of each silo rises from discharge of stored bulk solids. During discharge process, shell walls are highly prone to experience unsymmetrical pressure distribution that facilitates buckling occurrence. Actually, even during concentric discharge, unsymmetrical pressure distribution is inevitable [9]. It is also possible that discharge outlets intentionally located in some distance offset from the center line of the cylindrical silo as a part of the silo design.
EN 1991-4 [10] cover unsymmetrical nature of discharge loads by introducing patch load concept as a local pressures in addition to symmetric discharge pressure in design of silos. Accordingly, the discharge patch load shall be used to represent accidental asymmetries of loading during discharge, as well as inlet and outlet small eccentricities (less than $0.25d_c$, where $d_c$ is the diameter of the silo). Nevertheless, this should not be confused with the discharge loads for circular silos with large outlet eccentricities as defined in EN 1991-4 [10]. It is worth to notice that, Eurocode presents the most advance standard in design and analysis of steel silos and thus its relevant provisions on patch load are selected to be examined in this paper.
There are some past researches that partially addressed discharge patch load. Gillie and Rotter [11] conducted a research on the effect of patch load on the stresses in thin-walled circular silos. They performed linear analysis of a reference slender silo of uniform thickness by considering patch loads in shape of two squares and bell-shaped pressures. They showed that a patch load has the potential to produce significant von Mises stresses and compressive membrane stresses within the wall of a steel silo and can cause structural failure by either plastic collapse or elastic buckling. Song and Teng [12] analyzed a sample slender silo considering eccentric discharge loads proposed by four different codes: the German code [13], the ISO code [14], the part 4 of Eurocode 3 [15] and the Australian code [16]. The study showed that although the patch loads specified in these codes vary greatly from one code to another and may have a great effect on the linear bifurcation load, their effect on buckling loads determined using more sophisticated buckling analyses is small (i.e., when the effect of geometric non-linearity has been taken into account). Also, Song [17] carried out buckling analyses of a slender silo by taking geometrical non-linearity and material non-linearity into account. The