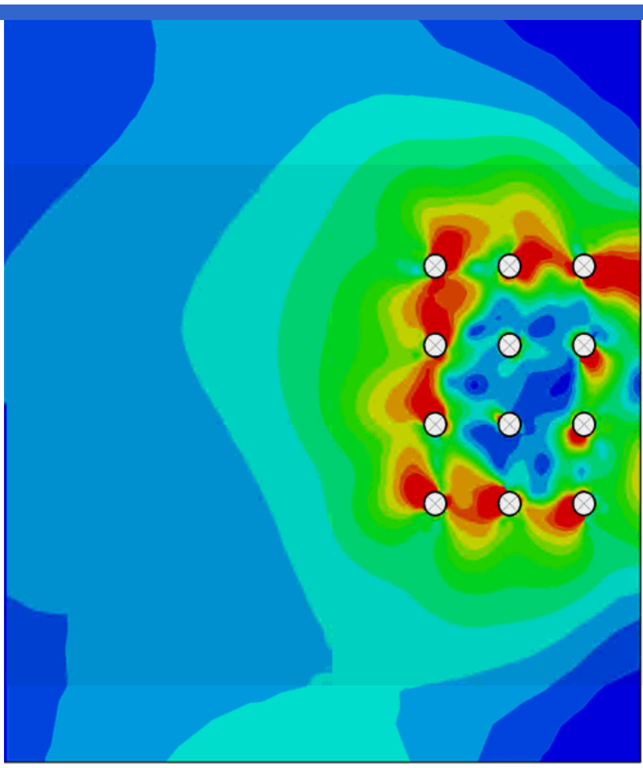
Capacity of Gusset Plate Connections



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Capacity of Gusset Plate Connections

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Preface

The present project is a master's thesis credited 35 ECTS points and written in the period from the 2nd of September 2013 to the 3rd of March 2014. The thesis concludes the Master of Science (M.Sc.) Degree in Civil Engineering at the Technical University of Denmark. The thesis and master education have both been carried out at the Department of Civil Engineering at the Technical University of Denmark.

Part of the project has been done in cooperation with *Jonatan Stær Nissen* as part of his bachelor's thesis which focuses on the experimental investigations of this present project.

The supervisors of this project has been Jeppe Jönsson, professor and head of section at the Department of Civil Engineering at DTU, and Jens Henrik Nielsen, lecturer at the Department of Civil Engineering at DTU. Furthermore the crew of the experimental facilities of the Technical University of Denmark has taken part in the experimental work. A special recognition goes out to all of the above mentioned for their help and guidance during the project period.

Kongens Lyngby, the 3rd of March 2014

Steen Winterskov-Andersen

Abstract

The capacity of gusset plate connections in steel structures is normally determined from a set of calculation standards. However the block tearing capacity is a subject that is not fully investigated for connections with a large eccentricity or a combination of forces. In this project the block tearing capacity of gusset plate connections is investigated, specifically with focus on the rotational capacity.

Nørgaard [1] developed a set of statically admissible plastic distributions describing the rotational block tearing capacity. An experimental setup was created to be able to test the validity of the theory, and a calculation program was made to verify the capacity of the experimental setup.

The theory for rotational block tearing capacity was investigated by 4 different experiments with varying amounts of eccentricity and combinations of loads. All of the experiments were shown to incite the desired rotational block tearing failure. Furthermore the general distribution of forces in the connection was seen to be as desired. The corner bolts were most critically loaded whereas the internal bolts did not contribute much to the capacity. However it was found that the theory suggested by Nørgaard [1] was inadequate in describing the limit value for the rotational bock tearing failure. The theoretical values were determined to be around 40% lower than the experimental values regardsless of eccentricity.

Previous experiments conducted on simple concentrically loaded connections has shown that the failure line is placed along the outer bolt edge lines with shear stresses and along the center-to-center line between bolts for lines with normal stresses. However, it was found from the experiments that the failure line placement was placed at the outer bolt edge for the connections affected eccentrically by a combination of loads. This was the case for all failure lines around the bolt group. Furthermore the experiments also showed a slight circular or ellipsoidal failure pattern and seemed to be affected by friction due to tightening of the bolts in the connection.

An optimized expression for the rotational block tearing was developed on the basis of the experimental results. It is suggested to use the failure lines along outer bolt hole edges. A simple expression for the friction was also taken into consideration. Furthermore, an optimized failure stress $f_m = \frac{f_y + f_u}{2 \cdot \sqrt{3}}$ was suggested on the basis of the work done by Driver et. al. [2]. The optimized expression increased the capacity of the rotational block tearing as desired. However the theoretic expression still underestimates the experimental values by about 15%. Therefore the theory still has some shortcomings and must be investigated further.

The general stress distribution and failure pattern observed from the experiments was confirmed by a 2-dimensional FE model of the experimental setup. Furthermore, this model also showed a slight circular failure pattern for the stress distributions.

The work curve for the FE model was seen to describe the experimental work curve with

reasonable accuracy for small displacements. However the model greatly underestimates the capacity for larger displacements compared to the experimental results. This was caused by an supposedly lacking material model and large discontinuities for the entire connection area.

Sammenfatning

Kapaciteten af laskepladesamlinger i stålkonstruktioner bliver normalt bestemt ud fra beregningsstandarder. Kapaciteten for blokudrivning er dog et emne der endnu ikke er undersøgt til bunds med hensyn til samlinger med store excentriciteter eller kombinationer af laster. I dette projekt vil denne kapacitet for blokudrivning blive undersøgt med henblik på specielt rotationskapaciteten af samlingen.

Nørgaard [1] opstillede et antal statisk tilladelige plastiske spændingsfordelinger, med det formål at beskrive kapaciteten for rotationsblokudrivning. Til dette projekt blev der lavet en forsøgsopstilling for at kunne teste denne teori. Yderligere blev der lavet et beregningsprogram som kontrol af forsøgsopstillingens kapacitet.

Teorien for rotationsblokudrivning blev undersøgt gennem 4 forskellige eksperimenter med variende excentriciteter og lastkombinationer. Det viste sig at alle eksperimenterne gav det ønskede brud som rotationsblokudrivning. I øvrigt var den generelle kraftfordeling i samlingen som forventet. Hjørneboltene i samlingen var mest kritisk belastede hvorimod det blev set at de indre bolte ikke bidrog mærkbart til kapaciteten. Det viste sig dog at kapaciteten bestemt ud fra teorien opstillet af Nørgaard [1] ikke beskrev den reelle kapacitet for rotationsblokudrivningen godt nok. Den teoretiske kapacitet blev bestemt til at være 40% lavere end de eksperimentelle værdier uanset excentricitetens størrelse.

Forsøg udført på simple, koncentrisk belastede samlinger har tidligere vist at brudlinien er placeret på ydersiden af boltene langs linier hvor der er forskydningsspændinger. Ved brudlinier med normalspændinger ligger brudlinien mellem boltehullerne, altså i center-til-center linien. Nærværende forsøg viste dog at *alle* brudlinierne var placeret på ydersiden af boltene for samlingerne der var påvirket excentrisk af en kombination af laster. Der viste sig også en tendens til et cirkulært eller ellipseformet brudmønster i samlingen. Udover det blev det set at friktion mellem de respektive dele i samlingen muligvis havde en effekt på grund af at boltene var strammet til.

Der blev på baggrund af eksperimenterne opstillet et optimeret udtryk for rotationsblokudrivningen. Til dette udtryk anbefales det at regne brudlinierne som placeret langs yderkanten af boltehullerne. Et simplificeret bidrag for friktionens effekt blev også medtaget i udtrykket. Desuden blev der brugt en optimeret værdi af brudspændingen. Denne brudspænding blev taget som kombinationen $f_m = \frac{f_y + f_u}{2}$ som foreslået af Driver et. al. [2] på basis af omfattende litteratur- og forsøgsstudier. Det optimerede udtryk øgede kapaciteten af rotationsblokudrivningen. Det optimerede teoretiske udtryk undervurderer dog stadig værdierne fra eksperimenterne med ca. 15%. Det er altså tydeligt at teorien har nogle mangler og bør undersøges yderligere.

Det generelle brudmønster og spændingsfordelingen af eksperimenterne blev bekræftet af en 2-dimensional FE model, der blev lavet af forsøgopstillingen. Denne model viste også en tendens til et cirkulært brudmønster.

Det blev set at arbejdskurven for FE modellen beskrev arbejdskurven for eksperimenterne med nogenlunde nøjagtighed for små flytninger. På den anden side undervurderer modellen i høj grad kapaciteten i forhold til eksperimenterne hvis der ses på større flytninger. Dette skyldtes muligvis en mangelfuld materialebeskrivelse samt store diskontinuiteter for stort set hele samlingens område.