THE INFUENCE OF THE PARTITIONING WEB PLATE ON THE INCREASE OF THE DUCTILITY OF THE SCS STRUCTURE

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ABSTRAKT

Tento článek se zabývá zvýšením duktility ocelobetonové sendvičové konstrukce v rovinném smyku vlivem přidání příčného plechu. Motivací pro zkoumání tohoto jevu je možnost návrhu konstrukce s vyšším poměrem vyztužení, který dle předchozího sledování duktilitu konstrukce naopak snižuje. Úvodem jsou představeny dva experimentální programy, které se vlivem příčného plechu v ocelobetonové sendvičové konstrukci zabývaly. Jeden experimentální program zahrnuje porovnání odezvy ocelobetonových panelů stejných geometrických i materiálových parametrů, přičemž jediným proměnným parametrem je přítomnost, respektive absence příčného plechu. Druhý experimentální program se zabývá čistě vlivem četnosti příčných plechů na duktilitu konstrukce při smykovém zatížení. Následně jsou rozebrány předpoklady o mechanismu chování ocelobetonové sendvičové konstrukce s příčným plechem a bez příčného plechu, které jsou následně podpořeny analýzou vlastních modelů za použití metody příhradové analogie a metody konečných prvků. Výsledkem této práce je hlubší pochopení mechanismu chování ocelobetonového sendviče s vlivem příčného plechu a dále také posouzení vhodnosti vyvinutých modelů příhradové analogie.

KLÍČOVÁ SLOVA

Ocelobetonový sendvič • Duktilita • Příčný plech • Model příhradové analogie • Numerické modelování

ABSTRACT

This paper deals with the increase in ductility of steel-concrete-steel sandwich in plane shear due to the addition of partitioning web plate. The motivation for investigating this phenomenon is the possibility of designing the structure with a higher reinforcement ratio, which, according to previous observations, decreases the ductility of the structure. Two experimental programs are introduced to investigate the effect of the partitioning web plate in a steel-concrete-steel sandwich structure. One experimental program involves a comparison of the response of steel-concrete-steel panels of the same geometric and material parameters, while the presence or absence of a partitioning web plate being the only variable parameter. The second experimental program deals purely with the effect of the frequency of partitioning web plates on the ductility of the structure under in-plane shear loading. Assumptions about the mechanism of behaviour of a steel-concrete-steel sandwich structure with and without a partitioning web plate are then discussed and supported by the analysis of own models using the truss and tie method and finite element method. This paper results in a deeper understanding of the behavioural mechanism of the steel-concrete-steel sandwich with the influence of the partitioning web plate, as well as an assessment of the suitability of the developed truss and tie models.

KEYWORDS

Steel-concrete-steel sandwich • Ductility • Partitioning web plate • Truss and tie model • Numerical modelling

1. INTRODUCTION

A steel-concrete-steel sandwich (SCS) structure consists of two external steel plates, which are anchored to infill concrete. The composite action is mostly provided by a combination of headed studs and tie bars.

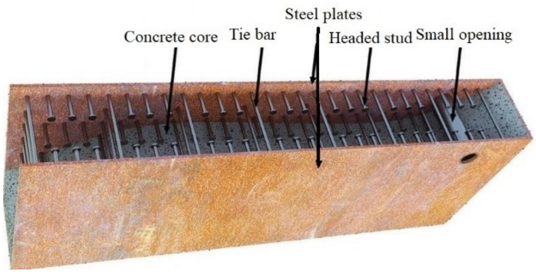

Figure 1 SCS structure

The area of use of SCS is principally in extremely loaded structures like protective structures, offshore structures, oil storage containers, ice-resistant structures, and containments of nuclear reactors. When structures like that are designed, a very high reinforcement ratio is often needed to satisfy static requirements and keep the thickness of a structure within reasonable limits. However, the code ANSI/AISC N690-18 (American Institute of Steel Construction, 2018) sets a limit of 5% maximum reinforcement ratio. The limit must be respected to provide the sufficient ductility of a structure. Ozaki et al.

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(2004) pointed out the relationship between ductility and the reinforcement ratio in SCS panels tests with reinforcement ratios ranging from 2.3% to 4.5%. They also found out that adding of a partitioning web plate can significantly rise the ductility of a structure, while the ultimate strength is preserved.

Zhang et al. (2019) focused on the effect of the frequency of partitioning web plates on the ductility of the structure under in-plane shear loading and found out that higher number of the plates leads to higher ductility of a structure.

This paper is focused on understanding of the behavioural mechanism of the steel-concrete-steel sandwich with the influence of the partitioning web plate. The aim is to determine the approximate value of the increase in ductility caused by the addition of the partitioning web plate. Based on this finding, it would be possible to increase the limit of the maximum reinforcement ratio.

2. EXPERIMENTAL PROGRAMS

2.1. The influence of the partitioning web plate

The experimental program by Ozaki et al. (2004) includes nine SCS panels. All the panels were 1200 x 1200 mm in in-plane dimensions and 200 mm thick. Five specimens were subjected to cyclic pure in-plane shear. Three of it had extern steel plates 3,2 mm thick, while the presence or absence of a partitioning web plate being the only variable parameter. One panel was designed without a partitioning web plate, the other was designed with a partitioning web plate and without any headed stud bolts, and the last one was designed with a partitioning web plate and with headed stud bolts on it.

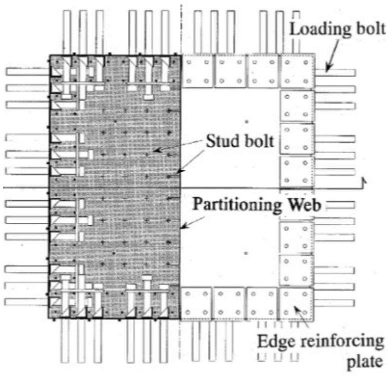

Figure 2: Specimen S3-00PS (Ozaki et al., 2004)

Uniform in-plane forces were applied to the panels using the shear bolts test facility (see Figure 3). The facility was comprised of a self-reacting frame containing eight hydraulic jacks.

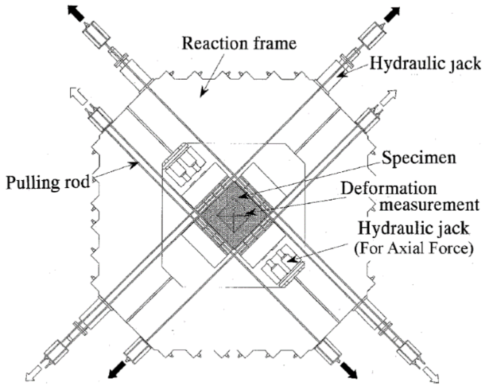

Figure 3 Test setup (Ozaki et al., 2004)

As can be seen from the responses of these three panels (see Figure 4), the addition of the partitioning web plate without the headed stud bolts caused increasing of a plastic shear deformation approximately three times, while the ultimate strength was maintained, and the yield strength was slightly reduced. It is also possible to observe that the addition of the partitioning web plate causes a smoother transition from the elastic part of the response to the plastic part.

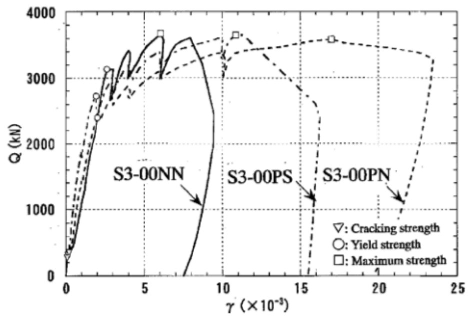

Figure 4 Comparison of specimen S3-00NN (without partitioning web), S3-00PS (partitioning web with stud bolts), S3-00PN (partitioning web without stud bolts) (Ozaki et al., 2004)

2.2. The influence of the number of partitioning web plates

The experimental program by Zhang et al. (2019) includes five types of SCS panels. Three of these panels were 1050 x 700 mm in in-plane dimensions and 120 mm thick with variable number of partitioning web plates from 2 pieces to 4 pieces. The others had variable thickness 105 mm and 135 mm and 3 pieces of partitioning web plates. The composite action of the external steel plates and the infill concrete in the space between the partitioning web plates is provided by headed stud bolts. All the panels had the same thickness of the external steel plates of 3 mm.

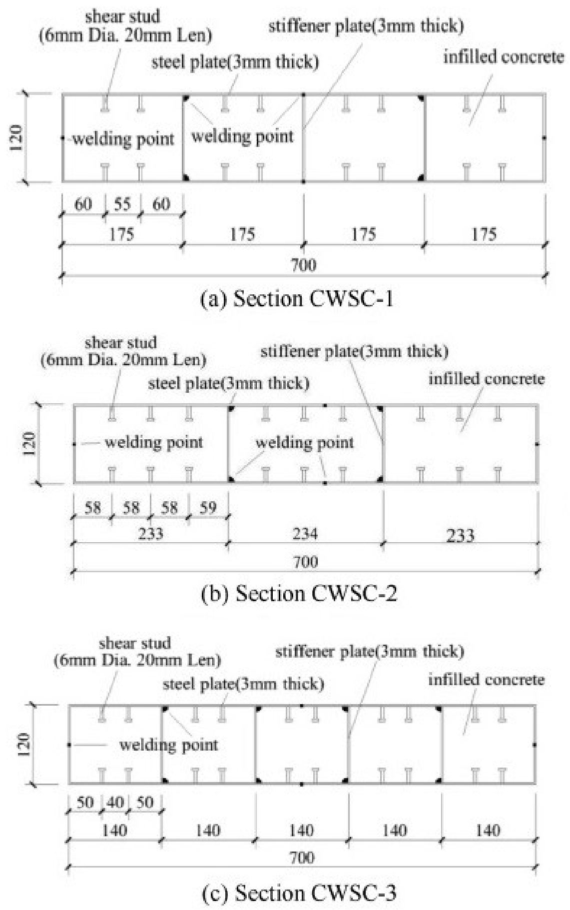

Figure 5 Cross section of the specimens (Zhang et al.,2019)

The specimen was laid between the top steel L-beam and the bottom steel beam, and the RC beams were fixed to the bottom steel beam and the top steel L-beam. The bottom steel beam was anchored to the ground, and the top steel L-beam was connected by three actuators, one in the horizontal direction and the others in the vertical direction.

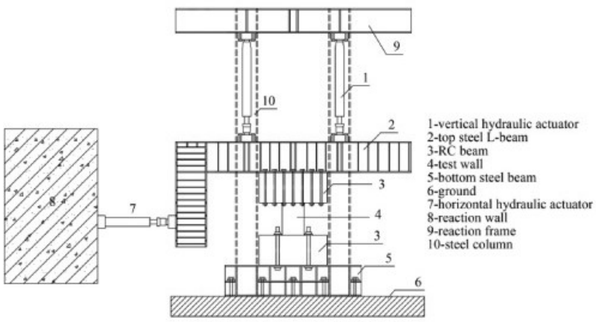

Figure 6 Test setup (Zhang et al.,2019)

When the in-plane shear responses of the panels with different number of partitioning web plates are compared, it is obvious that the higher number of partitioning web plates caused higher plastic shear deformation.

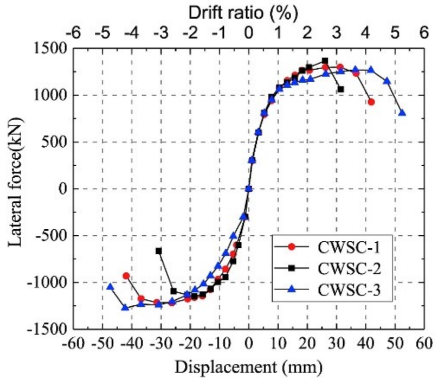

Figure 7 Comparison of specimen CWSC-1 (with 3 partitioning web), CWSC-2 (with 2 partitioning web), CWSC-3 (with 4 partitioning web) (Zhang et al.,2019)

3. BEHAVIOUR OF SCS PANELS - THEORY

Pure shear behaviour of a SCS structure with no partitioning web plate is quite simple. Pure in-plane shear can be understood as two principal forces of opposite nature (compressive and tensile) acting in the directions 45°, respectively 135°. When focusing on the in-plane shear response, three key moments can be recognized. The first one is when the concrete core is cracked in tension. The second one is when the external steel plates reach the yield point. The last key moment is when the concrete core is crushed in compression, which causes the collapse of the structure.

In the case of a SCS structure with partitioning web plate, the behaviour is a little bit more complex. The mechanism of a shear load transfer can be imagined as the combination of two phenomena. One phenomenon is pure shear behaviour of a SCS structure, and the other one is the effect of the slip between the concrete core and the partitioning web plate. In this case, five key moments of the in-plane shear response can be recognized, as it will be discussed in more detail in the next chapters.

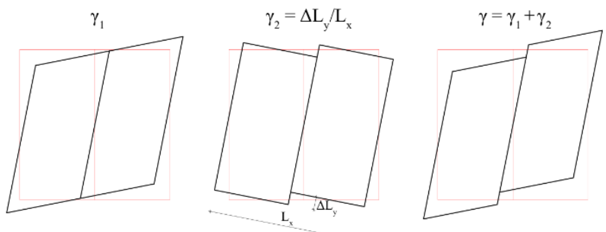

Figure 8 The scheme of two phenomena affecting the shear behaviour.

4. STRUT AND TIE MODEL

In the case of a SCS structure with no partitioning web plate, the strut and tie model is simple and suffices with just one strut and one tie, where the direction of a structure that carries the principal tension can be defined as the tie and the perpendicular direction that carries the principal compression can be defined as the strut.

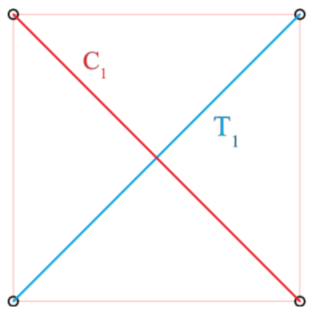

Figure 9 The strut and tie model for a SCS structure with no partitioning web plate.

On the other hand, in the case of a SCS structure with partitioning web plate, the strut and tie model has to be supplemented with an element that considers the slip between the concrete core and the partitioning web plate. The Author has decided to consider the slip by adding a horizontal element that is fitted with a support in the middle of its length to partly avoid rotation. The stiffness of the support should correspond to the material and geometric solution of the space close to the partitioning web plate.

If the SCS panel with the partitioning web plate from Ozaki´s experimental program is modelled by the strut and tie analogy, there should be defined two types of ties T_1, T_2 and two types of struts C_1, C_2. Nodes 1 and 1´, 2 and 2´ and 3 and 3´ are connected by the horizontal element, which includes the influence of the partitioning web plate. The horizontal element has the length *x*, which corresponds to the distance between the headed stud bolts nearest to the partitioning web plate.

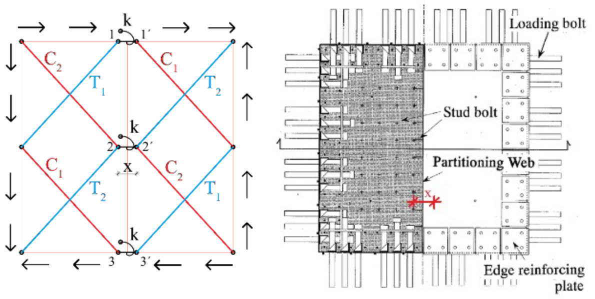

Figure 10 The strut and tie model for a SCS structure with partitioning web plate.

The stiffness *k* of the support can be determined for two eventual states of a structure. The value k_1 corresponds to the response of the structure in the nearest area around the partitioning web plate before the external steel plates reach the yield stress, while the value k_2 corresponds to the response after the external steel plates reach the yield stress.

5. NUMERICAL MODEL

5.1. Geometric parameters

All parts of the model are modelled using volumetric finite elements. The model is divided into two areas. In the normal area, elements of the concrete core and the external steel plates are fully fixed to each other, which represents the composite action between these layers. In the area near the partitioning web plate, a contact between the concrete elements and the steel elements is modelled by interface, which allows the slip with the influence of the friction. The load is applied through the edge reinforcing plates according to test setup.

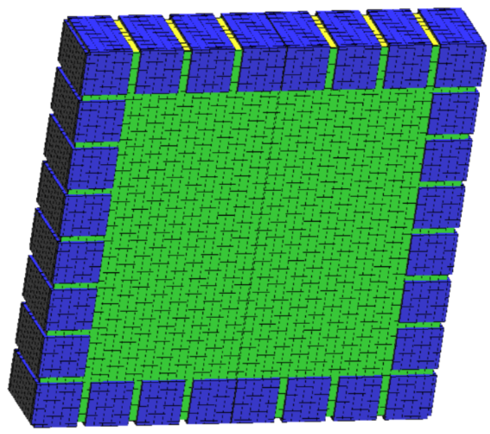

Figure 11 3D numerical model.

5.2. Material parameters

The most basic material parameters of steel (yield stress, Young´s modulus) and concrete (compressive strength, tangential stiffness) are taken from experimental measurements. The Poisson's constant was considered as 0.3 for steel and 0.2 for concrete. The rest of parameters, especially for concrete, were chosen to correspond to C40/50 strength class of concrete according to Eurocode 2 (EN 1992-1-1 Eurocode 2, 2002). The material of the edge reinforcing plates is considered as linear elastic with elastic modulus of 210 GPa.

5.3. Boundary conditions

The model is loaded by forces, which are applied on edge surfaces of the edge reinforcing plates. The increments of the load of 100 kPa are applied on every edge reinforcing plate in the direction of the forces, corresponding to pure shear.

Supports of the model should satisfy these conditions. It has to constrain the model enough to avoid instability but has to be released enough to enable extension of the model. According to that, every edge reinforcing plate is supported by plane springs with a stiffness of 1000 MPa in transverse direction of the edge of the model.

6. DISCUSSION

Two phenomena were measured on the numerical model. One was the in-plane shear response of the typical area, that is not affected by the partitioning web plate. The second one was the slip between the concrete core and the partitioning web plate. When these two responses are projected on the shear force-shear strain diagram, five key moments can be recognized.

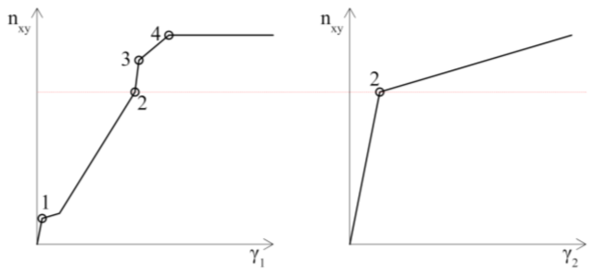

Figure 12 The in-plane shear response caused by the slip on the left, the in-plane shear response of the typical area of the model on the right.

The first one is when the concrete core is cracked in tension.

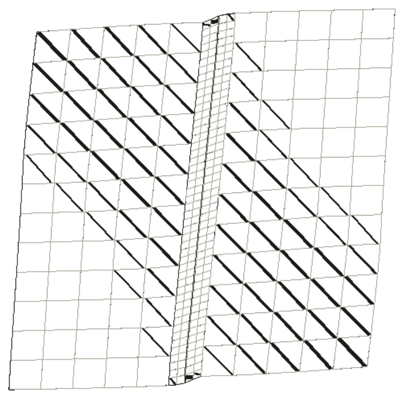

Figure 13 The crack pattern of the numerical model at the first key moment.

The second one is when the external steel plates in the area near the partitioning web plate reach the yield stress.

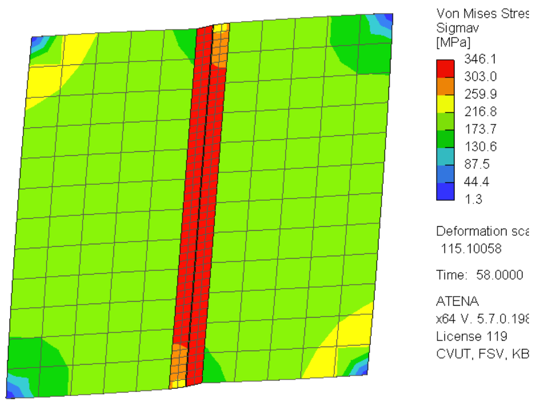

Figure 14 Von Mises stress of the external steel plates at the second key moment.

Since this moment the slip tends to increase faster, while the shear strain of the normal area tends to increase slower. At this point, the stiffness k of the support of the strut and tie model should change from k_1 to k_2.

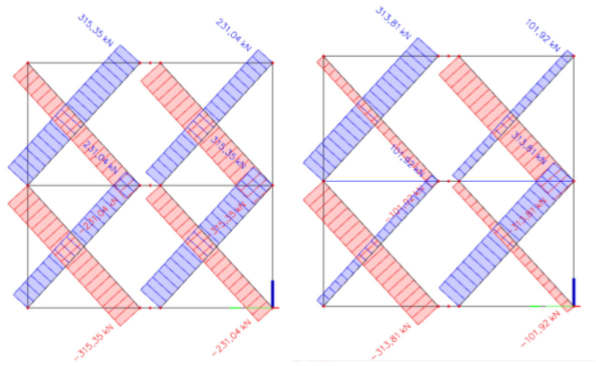

Figure 15 Forces in struts and ties before (on the left) and after (on the right) stiffness k is switched from k_1 to k_2.

The third moment is when the parts of the external steel plates, which are represented by the ties T_1 in the strut and tie model (see Figure 10), reach the yield stress.

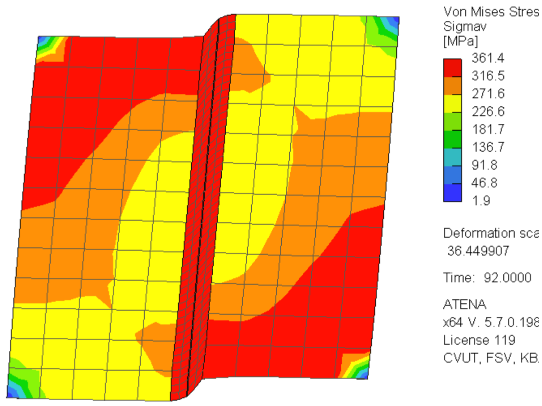

Figure 16 Von Mises stress of the external steel plates at the third key moment.

The ties T_1 are not able to carry any more load increments from this moment.

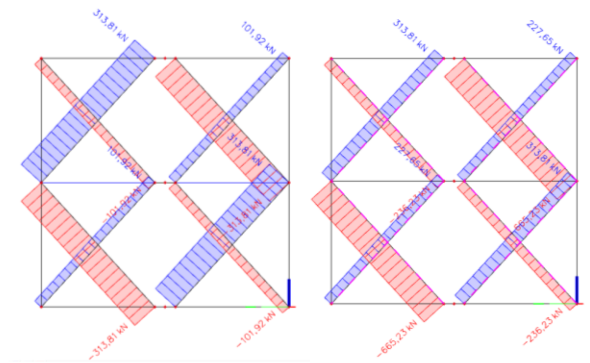

Figure 17 Forces in struts and ties before (on the left) and after (on the right) ties T_1 reach the yield point.

The fourth one is when the parts of the external steel plates, which are represented by the tie T2 in the strut and tie model, reach the yield stress.

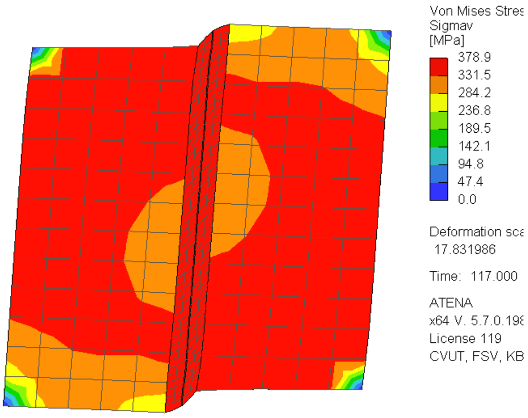

Figure 18 Von Mises stress of the external steel plates at the fourth key moment.

From this moment, the ties T_2 are also not able to carry any more load increments.

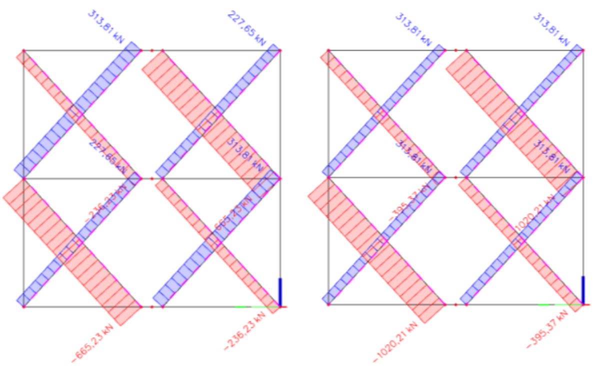

Figure 19 Forces in struts and ties before (on the left) and after (on the right) ties T_2 reach the yield point.

From this moment, struts C_1 and C_2 are the only elements capable of carrying further load increments. The panel collapses when the concrete core (struts C_1) crushes in compression.

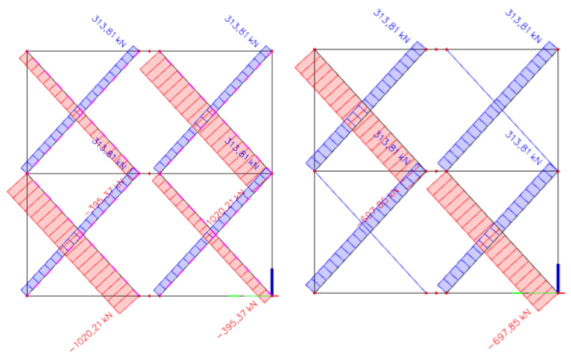

Figure 20 Forces in struts and ties before (on the left) and after (on the right) struts C_1 crush in compression.

7. CONCLUSION

Positive influence of the partitioning web plate on the increase of the ductility of the SCS structure has been demonstrated on two experimental studies. In the last chapter the behavioural mechanism of the SCS sandwich with the influence of the partitioning web plate has been analysed on numerical and strut and tie model. A good analogy can be seen in the behaviour of both models.

Further research of the topic with the aim to calibrate the response of the models will continue. The results will be applicable for the design of SCS sandwich structures with partitioning web plates.

ACKNOWLEDGEMENTS

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