Statens vegvesen

Norwegian Public Roads Administration

Energy absorption capacity for fibre reinforced concrete. Influence of friction in round panel tests with different support- and bedding conditions (Series 7)

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	TECHNOLOGY REPORT 2575
![logo] **Statens vegvesen**	**Title** **Energy absorption capacity for fibre reinforced sprayed concrete. Influence of friction in round panel tests with different support- and bedding conditions (Series 7)**
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Summary

The test program is part of the on-going revision of The Norwegian Associations publication no. 7 (Sprayed concrete for rock support), which among others is to be harmonized with the new European regulations for determination of energy absorption capacity of fiber reinforced sprayed concrete. The present test program involves round panels and is a study on different support- and bedding conditions and their effect on friction in panel tests.

A new modified support ring of steel was made specifically for the present tests. The motive was to give the support a more optimal design as a separate measure to reduce friction between the panel and the support. The tests make use of two support rings, the new modified steel support ring and, for comparison, the traditional wooden support ring. Totally five different support/bedding conditions were tested on 600 mm round, nominally identical, panels. The displacement rate in the tests was 3 mm/min.

Among the four individual test sets consisting of three or four panels the results show that the average coefficient of variation for the energy uptake between zero and 25 mm displacement was 8.8%.

The variable support- and bedding conditions had a great influence on the apparent energy uptake from the panel test. The overall energy uptake from the tests with wooden support confirms earlier results in the way that the accumulated friction effect is very high (here: 42% friction). The friction from the steel support was a bit lower, but still substantial (35%). Bedding of one layer of Teflon on steel support reduced the friction effect (18%) and bedding with two layers reduced it further (6%), but the latter result is uncertain as this set contains only one panel due to some logging error. Bedding of two PVC-membranes+grease is used as reference - it is assumed that there is no friction for this support condition.

Increasing friction appears to represent a reinforcing effect which generates a local strain-hardening behaviour in the panel around the contact-zone with the support. This is seen as local multiple cracking in this zone.

The Teflon suffered significant wearing during testing and had to be renewed in each test. A drawback with Teflon is that it makes the testing procedure more cumbersome as it gives extra work during the preparation of each test; more work naturally for two layers than for one layer. The bedding with PVC-membranes+grease has shown very effective to reduce/eliminate friction and is a good reference, but it is very laborious and can hardly be used in a standard procedure.

The trend is that friction also influences the maximum load during the test as well as the residual load at the end of the test; the effect is most evident for the latter.

The new rounded steel support did not give lower friction than earlier tests that used a steel support with a sharp inner edge.

Key words

Fibre reinforced sprayed concrete, energy absorption capacity, round panels, steel support, wooden support, type of bedding, effect of friction

Preface

The present test program is carried out as a part of the on-going revision of the Norwegian Concrete Association's publication no. 7 (NB 7): "Sprayed concrete for rock support"[1] (in Norwegian: "Sprøytebetong til bergsikring"), which, among others, is to be harmonized with the new European standards dealing with energy absorption capacity for fibre reinforced sprayed concrete. The new European standards describe square panels (continuous support), while the Norwegian tradition has been to test round panels (also continuous support) as described in the previous version of NB7. The program that has been undertaken is a comparative study of these two methods, but the program has also included some tests on ASTM round determinate panels. The present report gives the results from the seventh test series in this program.

During quality control the test panels shall, according to the standards, be sampled with the relevant concrete, personnel and spraying equipment (robot) for the given project. Some 10 years ago in Norway, it was decided to use round panels (600 mm diameter, 100 mm thick, net weight around 65 kg). These panels can be produced where the actual spraying work is done and they are experienced to be quite easy to sample and subsequently to be removed by two persons to a safer place in the tunnel.

According to the new European regulations (EN 14488 part 1 and part 5, [2][3]) large 1000 mm x 1000 mm (100 mm thick) panels shall be sprayed (net weight around 230 kg) and the panels shall not be removed the first 18 hours. After that, all further handling must be machine-based. Later in the laboratory, the panels shall be saw-cut in to a final size of 600 mm x 600 mm (net weight about 83 kg). By this rigorous procedure we fear that the connection between testing and practical application may be lost. It is also a big challenge to trim a 1000 x 1000 mm panel within the given tolerances for thickness.

The scope of the project was to study the practical consequences of the new regulations and to carry out comparative tests on energy absorption capacity on round and square panel tests. The results so far have revealed that panel tests are very influenced by friction between the panel and the support, and lately the project has been focused on this issue.

Cooperation is established with the contractor Entrepenørservice with regard to building of moulds and production of test panels. Members of the Norwegian Concrete Association's Sprayed Concrete Committee also contribute. The tests are performed in the Norwegian Public Roads' (NPRA) Central laboratory.

Up till now (2007-2009) seven test series have been carried through, all with field-produced concrete panels. Reporting so far from the previous test series can be found in [7]-[13]. The present report gives the results from "Series 7".

This time the panels were cast at the Økern-Sinsen road project, Oslo, as a cooperative work between the Norwegian Public Roads Administration (NPRA) and the contractor Veidekke Entreprenør AS.

Summary

A new modified support ring of steel was made specifically for the present tests. The motive was to give the support a more optimal design as a separate measure to reduce friction between the panel and the support. The tests make use of two supporting rings, the new modified steel support ring and, for comparison, the traditional wooden support ring. Totally five different support/bedding conditions were tested on 600 mm round, nominally identical, panels. The displacement rate in the tests was 3 mm/min.

Among the four individual test sets consisting of three or four panels the results show that the average coefficient of variation for the energy uptake between zero and 25 mm displacement was 8.8%.

The variable support- and bedding conditions had a great influence on the apparent energy uptake from the panel test. The overall energy uptake from the tests with wooden support confirms earlier results in the way that the accumulated friction effect is very high (here: 42% friction). The friction from the steel support was a bit lower, but still substantial (35%). Bedding of one layer of Teflon on steel support reduced the friction effect (18%) and bedding with two layers reduced it further (6%), but the latter result is uncertain as this set contains only one panel due to some logging error. Bedding of two PVC-membranes+grease is used as reference – it is assumed that there is no friction for this support condition.

Increasing friction appears to represent a reinforcing effect which generates a local strain-hardening behaviour in the panel around the contact-zone with the support. This is seen as local multiple cracking in this zone.

The Teflon suffered significant wearing during testing and had to be renewed in each test. A drawback with Teflon is that it makes the testing procedure more cumbersome as it gives extra work during the preparation of each test; more work naturally for two layers than for one layer. The bedding with PVC-membranes+grease has shown very effective to reduce/eliminate friction and is a good reference, but it is very laborious and can hardly be used in a standard procedure.

The trend is that friction also influences the maximum load during the test as well as the residual load at the end of the test; the effect is most evident for the latter.

The new rounded steel support did not give lower friction than earlier tests that used a steel support with a sharp inner edge.

Sammendrag

Forsøksprogrammet er gjennomført som et ledd i det pågående arbeidet med revisjon av Norsk Betongforenings publikasjon nr. 7 (NB 7) "Sprøytebetong til bergsikring", som bl.a. skal tilpasses de nye europeiske reglene for bestemmelse av energiabsorpsjonskapasitet for fiberarmert sprøytebetong. De utførte forsøkene startet som en sammenliknende studie av sirkulære og kvadratiske plateprøver. De nye europeiske standardene beskriver kvadratiske plateprøver (kontinuerlig opplegg), mens norsk tradisjon har vært sirkulære plateprøver (også kontinuerlig opplegg) som beskrevet i dagens NB7. Programmet som er igangsatt er en sammenliknende studie av disse to metodene, men programmet har også inkludert noen ASTM 3-punkts plateforsøk. Rapporten presenterer programmets syvende forsøksserie.

En ny modifisert oppleggring av stål ble laget spesielt til forsøkene. Motivet var å gi opplegget en mer optimal design for å gi mindre friksjon i forsøket enn det som er målt tidligere. Forsøkene omfatter to typer oppleggsringer, den modifiserte oppleggsringen av stål og den tradisjonelle treringen. Total fem ulike oppleggs/underlagsmateriale-betingelser er undersøkt i forsøkene på 600 mm runde, nominelt identiske, prøveplater. Nedbøyningshastigheten i forsøkene var 3 mm/min.

Blant de fire individuelle forsøkssettene som besto av tre eller fire plater viser resultatene at gjennomsnittlig variasjonskoeffisient for energiopptaket mellom null og 25 mm nedbøyning var 8,8%.

De ulike oppleggs/underlagsmateriale-betingelsene hadde stor betydning på det målte energiopptaket fra forsøket. Akkumulert energiopptak for forsøkene med trering bekrefter tidligere resultater på den måten at friksjonseffekten er svært høy (42%). Stålringen gir litt lavere friksjonseffekt, men effekten er likevel vesentlig (35%). Ett lag Teflon (stålring) som underlagsmateriale reduserte friksjonseffekten (18%) og to lag Teflon ga ytterligere reduksjon (6%), men sistnevnte resultat er usikkert ettersom forsøkssettet består av bare en plate (pga. loggefeil på de andre platene). Underlagsmaterialet bestående av to lag PVC-membraner+grease er brukt som referanse; det er antatt at det ikke er friksjon i forsøket når dette brukes.

Økende friksjon synes å gi en "armerende" effekt som genererer "strain-hardening"-oppførsel i prøveplaten rundt kontaktsonen med opplegget. Dette observeres som "multiple cracking" i denne sonen.

Teflonen som ble brukt som underlagsmateriale ble slitt ned under forsøket og måtte byttes ut før hvert forsøk. En ulempe med Teflon er at selve forsøksprosedyren blir mer tungvindt ettersom det medfører ektraarbeid under forberedelsene til hvert forsøk. To lag Teflon medfører naturligvis mer arbeid enn ett lag Teflon. Underlagsmaterialet med PVC-membraner+grease har vist seg svært effektivt til å redusere/fjerne friksjon og er en god referanse, men systemet er svært arbeidskrevende og kan neppe brukes i en standard prosedyre.

Trenden er at friksjon fra opplegget også påvirker maksimumslasten i forsøket i tillegg til restlasten ved slutten av forsøket; effekten er mest markant for sistnevnte.

Den nye avrundede stålringen ga ikke lavere friksjon i forsøket enn tidligere forsøk som er utført med en stålring som ikke var avrundet.

Content

1   Introduction

Previous tests have shown that when the concrete panel is put directly on a continuous support the energy absorption result is greatly influenced by friction. This holds both for wooden support (according to NB7 [1]) and for steel support (according to EN 14488-5 [3]). The friction effect for wooden support has been reported in [10][11] ("Series 4"), whereas the friction effect for steel support has been studied in another, presently unpublished, test series ("Series 6") [13].

A central point in the discussions in the Norwegian Sprayed Concrete Committee has been that we need to have control of the friction effect in panel tests; either must the friction be eliminated or it should be known and under control. This means that the support conditions (including possible bedding material) should be unambiguous, reproducible and easy to describe and perform. In addition to having the direct effect of giving an extra (and erroneously) energy uptake in the test, friction may even change the crack pattern (it may increase the number of cracks and also initiate shear failure) which, in its turn, also influences the energy uptake during the test. This illustrates the importance of controlling friction in panel tests and that it should be as low as possible.

Support of steel is apparently better in the sense that the wearing resistance is higher, and this is the reason why steel support has been brought into our investigations, and also that fact that steel support is described in the European standard EN 14488-5 (square panel test). To our knowledge, the documentation of the friction effect (and its invariability) for steel support is presently absent in the literature. Any description of test procedure for panel tests should be very precise with regard to the support- and bedding materials and practical execution. Presently this is not the case.

The major scope of the present work was to study the effect of a modified steel support ring as well as Teflon as measures to reduce/control friction in panel tests. Teflon is used as bedding material between the concrete panel and the support. Teflon is a well-defined commercially available material which could, if proven useful, be described as bedding material in a standard test procedure. According to the data sheet the coefficient of friction for Teflon-steel is very low (Teflon-concrete friction is not given). Possible disadvantages for Teflon are, however, that the mechanical strength and wearing resistance is not superior.

A new modified support ring of steel was made specifically for the present tests. The motive was to give the support a more optimal design as a separate measure to reduce friction. The tests make use of two supporting rings, the new modified steel support ring and, for comparison, the traditional wooden support ring. Totally five different support (friction) conditions are tested on 600 mm round panels. The applied displacement rate was 3 mm/min in the present tests, which is somewhat higher than standards describe today (1.5 mm/min in [1] and 1.0 mm/min in [3]). The influence of the displacement rate on panel test results is insignificant for these displacement rates [6] and a higher displacement rate was therefore chosen to shorten the test duration for each panel. For the rate 3 mm/min each test takes only 10 min since the final displacement in the test is 30 mm.

2 Modified steel support and wooden support

2.1 New modified rounded steel support ring

In the previous test series ("Series 6", [13]) it was seen that the round steel support penetrated (1-2 mm) into the concrete panel during testing. As shown in Fig. 2.1 the footprints of friction caused by the sliding of the panel on the steel support were clear. The sliding occurs in two directions, radial and tangential, and is about the same in both directions (discussed closely in [10]). The steel support that was used in these previous tests was made according to the European standard for square panels (EN 14488-5, [3]), i.e. the support had a rectangular cross section with inner diameter=500 mm and thickness=20 mm. The results showed that the effect of friction on the energy absorption results was significant (28% of the apparent energy uptake was due to friction). Those tests [13] were on round panels (and a round support ring) and not on square ones as described in the European standard, but we have today no reason to believe that round or square panel test give different results [7][8][9]. Hence, the friction effect should therefore also be the same for the two panel geometries.

Prior to the present investigation a modified steel support ring was made. The steel support ring is rounded at the inner top edge. Plan drawing and cross section of the ring is given in Fig. 2.2-a and Fig. 2.2-b, respectively, while Fig. 2.3 shows two pictures. The motive for rounding the inner top corner was to reduce the tendency of the steel ring to penetrate into the concrete panel during testing, and in this way to reduce friction; the radial friction perhaps in particular. The thickness (t) of the ring is 25 mm, with rounding (radius r = 20 mm) over the outer 5 mm of the top corner. Hence, when the panel is placed on the ring the initial open span (inner diameter) is 500 mm.

In contrast to a support with an inner top edge shaped as a 90° corner, it is notable that the given rounding of the corner means that the contact-point to the panel will slightly change during loading and rotation of the panel, see Fig. 2.4. At the end of these tests the final displacement is 25 mm, hence
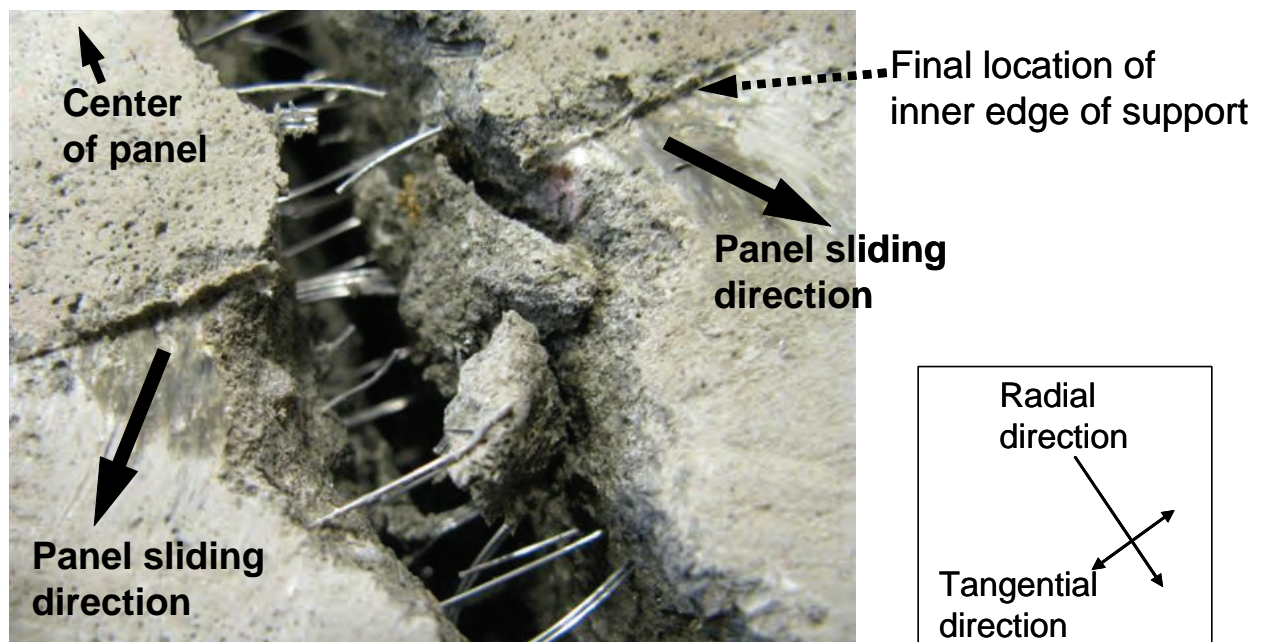

Fig. 2.1 Panel under-side after end of test at the contact zone between steel support and a crack. From a previous test series, Series 6 [13]

the maximum angle of rotation (Θ) is $(25/250)\tan^{-1} = 5.7^{o}$, as the lever arm is 250 mm (ignoring the small effects quantified below). Presuming that there is no crushing of the concrete panel at the contact-point with the support, the total movement of the contact-point in horizontal (lever arm) and vertical direction can then be approximated:

Equation 1   Total horizontal movement $= r\sin\Theta = 20\text{mm}\sin(5.7^{o}) = 2.0\text{mm}$

Equation 2   Total vertical movement $= r(1-\cos\Theta) = 20\text{mm}(1-\cos(5.7^{o})) = 0.1\text{mm}$

The horizontal movement of the contact-point means that the lever arm decreases from 250 mm at test start to (250-2=) 248 mm at the end of the test, hence the lever arm is reduced totally 0.8%. The average lever arm for the whole displacement range is 249 mm (0.4% reduction). The vertical movement, in total 0.1 mm, constitutes a small extra load train of the support (totally 0.4% at 25 mm final displacement, but only 0.1% as an average for the whole displacement range). Compared to a support with an inner top edge shaped as 90°, these horizontal- and vertical movements, when not corrected for, have minor influence with regard to the measured energy absorption in a test.
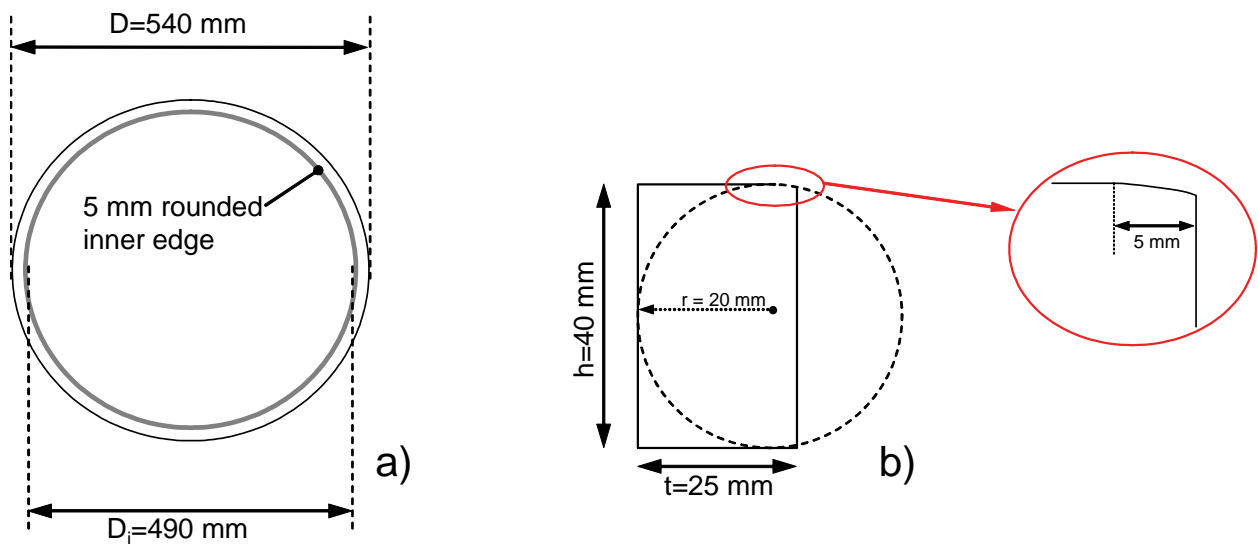
Fig. 2.2 New rounded steel support ring: Plan drawing (a) and cross section with the inner-side to the right (b)
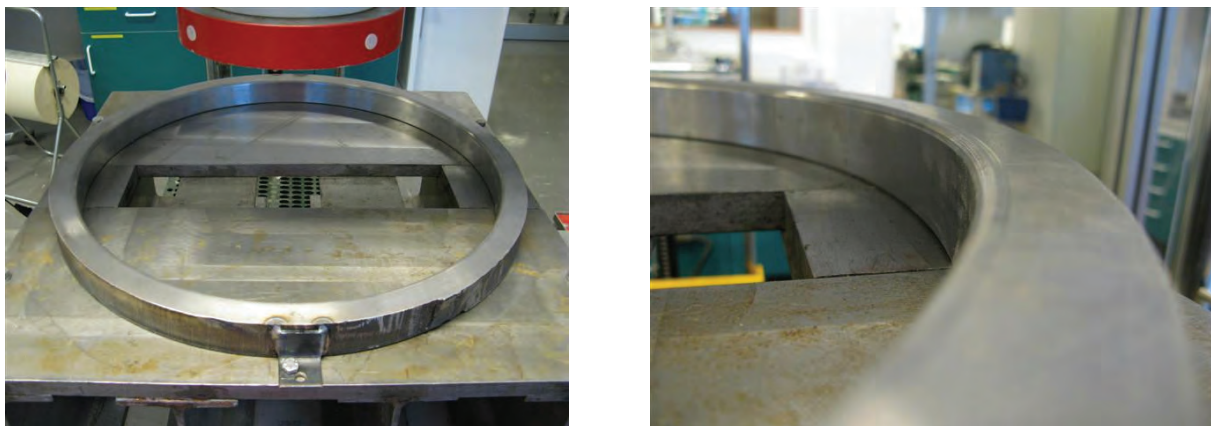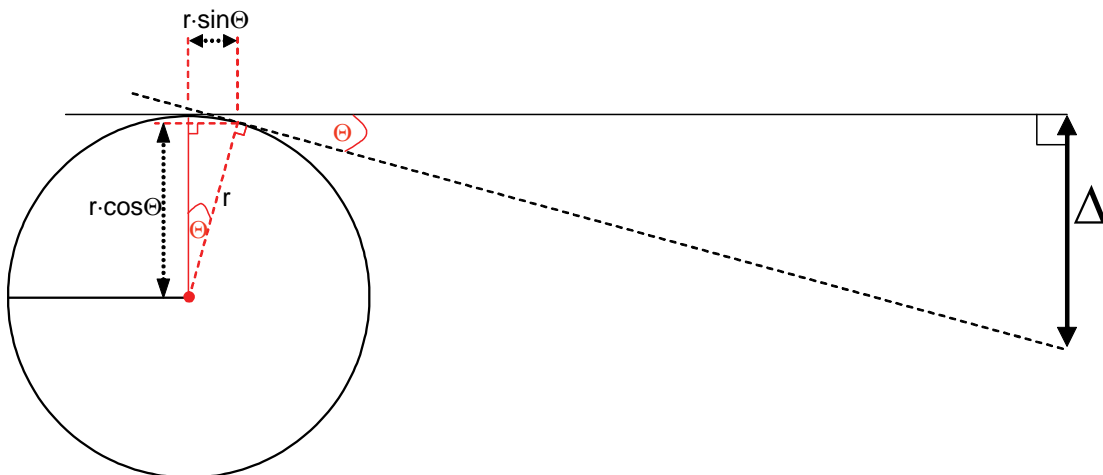

Fig. 2.3 Pictures of the new rounded steel ring

Fig. 2.4 Illustration of change of the support-panel contact-point during a displacement Δ at the centre of the panel and a corresponding rotation Θ.

2.2   Wooden support ring

The wooden ring that was used is the traditional ring used in Norway during the last decade [1]. The ring is made of birch and has inner diameter = 500 mm and outer diameter = 600 mm (and 40 mm high), see Fig. 2.5.
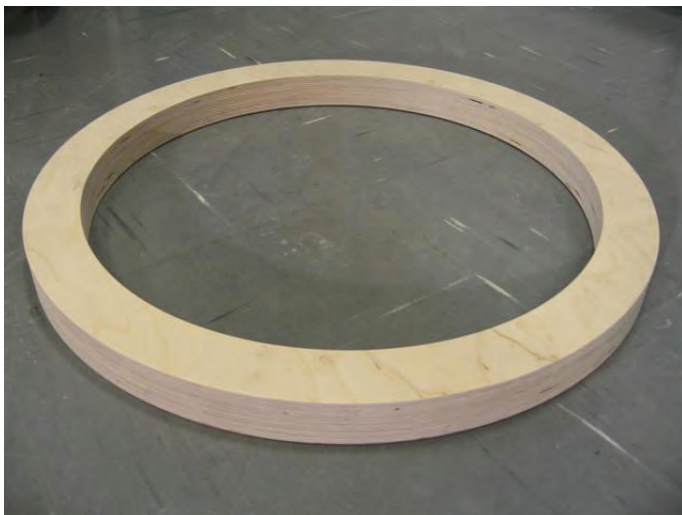

Fig. 2.5 Picture of the wooden ring made of birch.

3   Test program

The following measurements were performed:

- Fresh concrete slump and air content were mesured at the casting site.
- Fresh concrete fibre content: Two samples were taken, one at the beginning and one at the end of casting, and transported to the laboratory were the measurements were done.
- Compressive strength: Four cubes were cast for testing after 7 days (two cubes) and 28 days (two cubes).

- Round panel (Ø600 mm, thickness=100 mm) energy absorption capacity tests on 18 cast panels (some panel tests failed, see ble 1). The age of the concrete panels at testing were 28 days. In order to study the effect of friction the tests were performed with different support- and bedding materials, see ble 1. The plan was that each test set should contain three panels.

ble 1: Test program for the energy absorption capacity tests. Panel numbers in parenthesis mean that the result from the panel test was lost due to logging error.

Support	Test set	Bedding material	Panel number	
Rounded steel support	3	No bedding	4, 9, 15	
	1	One layer of Teflon	2, 11, 17	(1, 12)
	5	Two layers of Teflon	13*⁾ , 18	(6)
	2	Two layers of PVC-membrane + grease	3, 7, 10, 16	
Wooden support	4	No bedding	5, 8, 14	

*⁾ *The data beyond 10 mm displacement was lost due to logging error.*

Prior to testing, the laboratory had installed a new computer with the program for test control and data logging. Some start problems with the computer is the reason why some of the panel tests results were lost (even though the panels apparently were loaded and tested successfully). Unfortunately, the set that was tested at the end, Set 5 with two layers of Teflon, only contains one fully successful panel test. Set 4 contains four panels.

The panels were numbered successively during casting, hence panel 1 was cast first, panel 2 second, etc, and panel 18 was cast at the end. During testing the idea was that each test set was to contain panels that were spread over the casting sequence (to compensate for possible changes in fibre content). The "test set" number indicates the order in which the sets were tested.

The panels in Set 2 with bedding of two layers of PVC-membrane + grease was in a previous tests series ("Series 4" [10][11]) denoted "no friction conditions". This test condition is shown to give very little friction and is used as reference against which the other test sets are compared. Furthermore, the condition in Set 4 with wooden support and no bedding material was in the previous tests denoted "Standard conditions" since it is the method described in today's NB7 [1] and used traditionally in Norway.

The used Teflon layer has a thickness of 0.5 mm and the given value for coefficient of friction against dry steel is 0.08, see data sheet in APPENDIX 1. The coefficient of friction against concrete is not given. The data sheet for the PVC-membrane is also given in the same appendix.

4   Concrete mix, casting and curing

4.1   Concrete mix

The mixing of the concrete was done 30th of September at the ready-mix plant of NorBetong at Alnabru, Oslo. The concrete was then transported by concrete truck to a nearby construction area (the Økern-Sinsen project) where the casting took place in a tent.

The nominal recipe of the basic sprayed concrete mix is given in Table 2. The concrete was cast, hence no accelerator was added. The nominal (effective) water-to-cement ratio (w/(c+2s)) is 0.42. The nominal dosage of the macro PP-fibre is 7 kg/m^3. The PP-fibre is "continuously embossed" and 48 mm long. Data sheet for the fibre is given in APPENDIX 2.

Table 2: Nominal concrete mix

Material	Type/producer	Kilo pr. m^3 concrete
Cement	Norcem Standard FA Cem II/A-V 42.5R	483.5
Silica fume(k=2)	Microsilica	20.1
Sand, 0-8 mm (I)	Høisand	741.5
Sand, 0-8 mm (II)	Høisand	741.5
Macro PP-fibre	BarChip Kyodo	7.0
Superplasticizer	Sika Viscocrete FB-2	6.0
Interncure	Mapequick CCI-2000	5.0
Free water		220,0
Mass ratio	w/(c + 2s)	0.42
Nominal density		2208

4.2   Casting and curing of panels

Totally 18 round panels were cast; all panels with nominal dimensions of 600 mm diameter and 100 mm thickness. The 18 moulds were collected among the members of the Norwegian Sprayed Concrete Committee, involving four different types of moulds, see Fig. 4.1. Pictures from the casting and de-moulding are shown in Fig. 4.2 and Fig. 4.3. The contractor Veidekke Entreprenør AS accommodated the concrete by delivering the concrete from a truck, while people from NPRA carried out the casting work and the subsequent de-moulding, transport and laboratory testing.

The concrete panels were cast and afterwards covered with a plastic sheet to avoid moisture loss. After 1.5 days of curing on-site the panels were numbered according to their place in the casting sequence (from 1 to 18), de-moulded, and transported to the laboratory were they were cured in water baths until the day of testing. The compressive strength cubes experienced exactly the same handling regime.
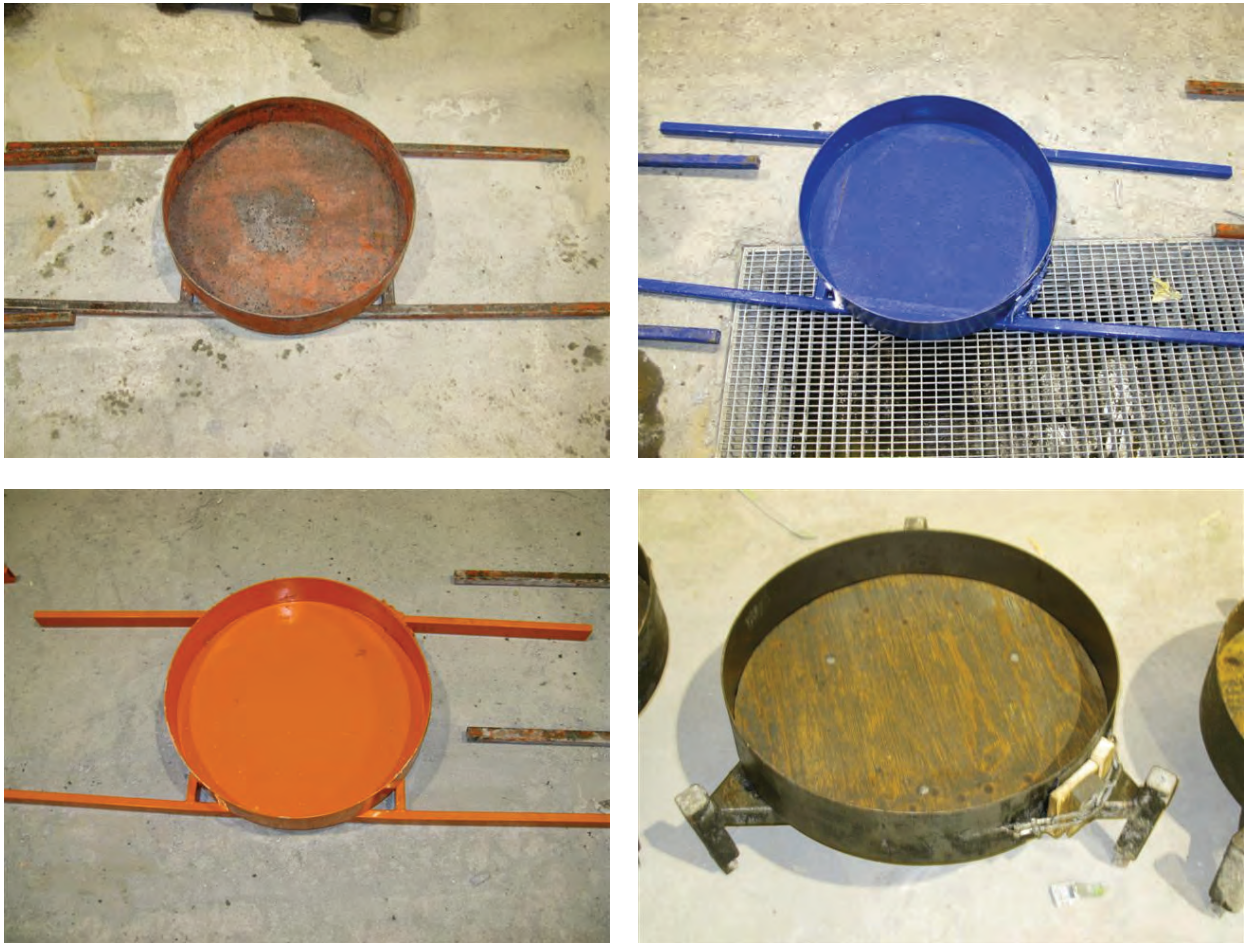
Fig. 4.1 The various 600 mm panel moulds

Fig. 4.2 Arrival of the concrete truck and loading of concrete (left). The 18 panels after end of casting and covering with plastic foil (right)

Fig. 4.3 De-moulding after 1.5 days.

5 Test methods and -procedures

5.1 Air content

Air content was measured in fresh concrete, standard method [4].

5.2 Fibre content

Two samples, one taken at start of casting and one at the end, were taken and transported to the laboratory. Each sample contained 5 litres of concrete. The weight of the samples was measured. The concrete from the each sample was then taken out, in portions, and washed over a 2 mm sieve. Most fibres collect at the top of the sieve, but some go through. Most PP-fibres going through the sieve float, but some sink with the rest of the materials; these are found by extra stirring and manual searching. After picking all the fibres they were washed one extra time in clean water. The fibres from each sample were then spread out on paper in order to dry over-night.

The next day the fibres were investigated manually in order to spot possible particles fastened to the fibres and, for ensuring total dryness, the fibres were treated with a hair-dryer. The weight of the dry and clean fibres was determined and the ratio fibre content (gram) to concrete volume (litre) was calculated. The procedure is in accordance with EN 14488-7:2006 [5].

5.3   Compressive strength

100 x 100 mm cubes were tested according to standard procedure (load rate = 0.8 ± 0.2 MPa/sec) [4].

5.4   Energy absorption capacity

5.4.1   Test rig

The test set-up is shown in Fig. 5.1. A load plate (Ø100 mm cylindrical steel plate) was put between the central oriented load cell and the specimens (+ a thin sheet of cardboard). The central displacement of the panel was measured by a displacement transducer as shown in Fig. 5.2. The transducer is spring-loaded and of the type "ACT1000A LVDT Displacement Transducer" from RDP Group. The measuring range is 50 mm. The test machine (FORM+TEST Delta 5-200 with control system Prüfsysteme Digimaxx C-20) has a maximum load of 200 kN and stiffness > 200 kN/mm.

The deformation rate during the test is controlled by the signal from the displacement transducers under the panel. Prior to the test, the load-cell is stabilized at a load of 1 kN. With this initial load the test is started. The displacement rate during the test was 3 mm/min.

Fig. 5.1 Set-up for the energy absorption tests. Left: modified steel support (with Teflon bedding). Right: wooden support.

Fig. 5.2 Measurement of central displacement at the bottom side of the panel by the use of a spring loaded displacement transducer (LVDT) with a disc on top which can rotate along with the rotation of the panel, as well as bridging over the cracks.

5.4.2 Test procedure

Prior to testing, each panel was taken out of the water bath and transported to the test rig. The test started within 45 minutes.

The procedure was then as follows:

1) The panel was placed in the test rig with the smooth moulded face against the support fixture.
2) Bedding material (when used): The bedding material was prepared in two pieces. The panel, resting on the support, was lifted halve-way from one side at the time and the pieces of bedding were put between the panel and the support.
3) The panel was centred
4) The displacement transducer was placed under the centre of the panel.
5) On the upper side of the panel (the cast side) the load plate was placed at the centre (+ a thin sheet of cardboard).
6) The load cell was prepared for testing by lowering it to the load plate until a load of 1 kN is applied to the panel.
7) The test was started and load- and deflection signals were logged continuously by a computer. The displacement rate was controlled by the computer to be 3 mm/min.
8) The test is stopped automatically when the central deflection is is 30 mm.
9) The panel was then lifted out of the test rig, and the whole bottom side of the panel was photographed in order to document the crack pattern. For most panels also each crack was photographed in the area that had contact with the support. If the panel suffered shear blocking also the top side of the panel was photographed.
10) Later each panel was completely broken into pieces along the cracks, and over each cracked surface 3 thickness measurements were made, totally 12 measurements per panel. The thickness was measured with a digital sliding calliper.
11) The energy absorption capacity was then calculated as the area under the load-deflection curve from zero to 25 mm deflection. The results were corrected for thickness when deviating from 100 mm, see Section 5.4.4. The results were not corrected for early non-linearity in the load-deflection record since earlier analyses [10] revealed that the effect of the correction on our results was insignificant.

5.4.3   Bedding materials and execution

<u>No bedding</u>

The panel was placed directly on the modified steel support or the wooden support, see Chapter 2.

<u>One or two layers of Teflon as bedding material</u>

Adequate lengths of Teflon was cut from a roll of Teflon, see Fig. 5.3. The mid part of each Teflon sheet oriented towards the centre of the panel was removed to ensure an open space for the displacement transducer during testing. Product data for the Teflon is given in APPENDIX 1. The cost for one layer Teflon sufficient to cover the support in one panel test was around 25 Euro (NOK 200).
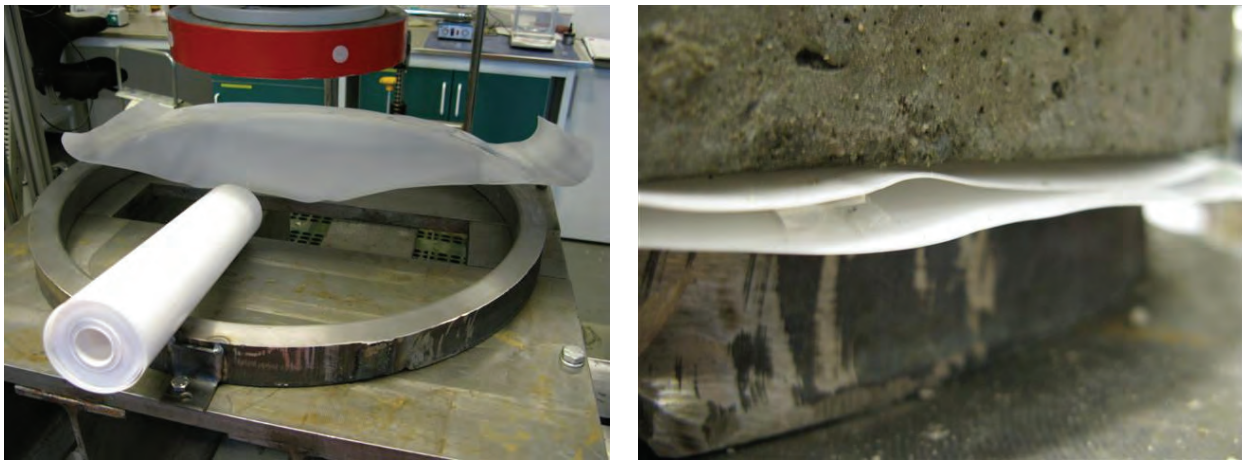
Fig. 5.3 Teflon as bedding material. Preparation (left) and example of using two layers of Teflon as bedding (right).

<u>Two layers of PVC-membranes and grease as bedding</u>

This bedding consists of two PVC-membrane layers with grease in between, see Fig. 5.4, similar to that reported from the previous Series 4 [10][11]. The bottom ring-shaped membrane was well covered with grease, while the top membrane (in contact with the concrete panel) was cut from inside and outwards into "fingers" (about ¾ of the width). The cut membrane was then placed on the bottom membrane into a "sandwich". The "fingers" were made to enhance the ability of the crack edges to slide freely in the tangential direction, while the grease is favourable in reducing friction in both tangential- and radial direction. In the previous Series 4 it was shown that this bedding reduced friction to a minimum.

5.4.4   Evaluation of results / correcting for deviating thickness

The energy absorption capacity of the panel shall according to the standards be calculated as the energy uptake between 0 and 25 mm central deflection during a fixed deflection rate. The panel thickness influences the ability to take up energy, where increased panel thickness will increase the energy uptake, and vice versa. Consequently, the calculation of energy absorption capacity should be corrected for when the thickness is deviating from the reference thickness. A theoretical evaluation of the effect of panel thickness was done in [14]. Target panel thickness is in our case $h_0 = 100$ mm. The following analysing procedure was proposed for panels with thickness h deviating from h_0:

Fig. 5.4 Two layers of PVC-membranes and grease as bedding material. Preparation of grease on the bottom membrane layer (left), the cut membrane is placed on top (top right) and slide freely during testing (bottom right).

1. Accumulated energy should be calculated under the load-displacement curve between 0 and a modified displacement $\Delta_m = 25$ mm $\cdot$ k, and $k = 100/h$
2. Calculated EAC should then be multiplied with the factor k.
3. The final corrected EAC is then the result from the test.

The procedure assumes that the moment capacity in the crack is linearly related to the thickness of the panel and the rotation of the crack. It is likely that the correcting procedure will be valid within reasonable variations in panel thickness and that it will certainly contribute to achieving more comparable results.

What the procedure does is really to normalize the cross section of the yield lines, in horizontal direction by point (1) and in vertical direction by point (2). The following formula is then used to calculate the corrected energy absorption capacity (EAC) in each test:

Equation 3
$$EAC = k \sum_{i=0}^{i=\Delta_m} \left[\left(\Delta_{i+1} - \Delta_i \right) \frac{P_i + P_{i+1}}{2} \right]$$

where k and Δ_m are explained above. Δ is the central displacement, P is the central load and the parameter i is the increment number.
All presented results are corrected according to the above procedure. In the present investigation the panels had average thicknesses ranging from 98 mm to 109 mm, see APPENDIX 3.

6 Results – supporting tests

6.1 Slump and air content

Fresh concrete slump and air content were measured to be 220 mm and 8.5%, respectively.

6.2 Fibre content

The two measurements of fibre content in fresh concrete gave 8.7 and 7.6 kg/m^3. Hence, average fibre content was measured to be 8.2 kg/m^3. The nominal fibre dosage was 7 kg/m^3.

6.3 Compressive strength

The four 100x100 mm cubes were tested at 7 and 28 days concrete age. The results are given below.

Table 3 Compressive cube strength (MPa) after 7 and 28 days

	7 days	28 days
Cube 1	39.5	57.0
Cube 2	39.5	56.5
Average	39.5	56.8

The average density measured on the cubes was 2170 kg/m^3.

7 Results and discussion - Panel tests

7.1 Panel thickness

All thickness measurements are given in APPENDIX 4. The average panel thickness for all panels was 102 mm. Panel thicknesses varied from 98 mm to 109 mm. For the thickness measurements on each individual panel the standard deviation varies from 0.5 mm to 4 mm, while the average std.dev. for all individual panels is 2 mm. The panel thickness is corrected for when calculating the energy absorption capacity for each panel, according to the procedure described in Section 5.4.4.

7.2 Energy uptake

7.2.1 Variability

For each set of panels the coefficients of variation (COV) for the accumulated energy uptake up to 25 mm and 5 mm central panel displacement are shown in Table 4 and Table 5, respectively.

Table 4: Accumulated results up to 25 mm displacement.

Support	Test set	Bedding material	Average accumulated energy uptake [Joule]	Coefficient of variation COV	Average friction effect
Rounded steel support	3	No bedding	939	6.7%	35%
	1	One layer of Teflon	746	6.7%	18%
	5	Two layers of Teflon	652	*)	6% *)
	2	Two layers of PVC-membrane + grease	613	17.4%	0% Reference
Wooden support	4	No bedding	1052	4.5%	42%

*) *Note: This set contains only one panel.*

Table 5: Accumulated results up to 5 mm displacement.

Support	Test set	Bedding material	Average accumulated energy uptake [Joule]	Coefficient of variation COV	Average friction effect
Rounded steel support	3	No bedding	230	1.9%	39%
	1	One layer of Teflon	206	6.0%	32%
	5	Two layers of Teflon	162	*)	13%
	2	Two layers of PVC-membrane + grease	140	23.3%	0% Reference
Wooden support	4	No bedding	202	13.2%	31%

*) *Note: This set contains only one panel.*

The set with two layers of Teflon unfortunately contains only one panel due to logging error during the two other panel tests in this set. Average COV for the energy uptake up to 25 mm displacement is 8.8% for the remaining four individual sets containing three or four panels. Similarly, the average COV for energy uptake up to 5 mm displacement is 11.1%. It is notable that the COV for the set with bedding of PVC is much higher (COV=17.4% for 25 mm displacement) than the other sets, but it is not unnormal as such high COVs have been seen also in some previous test sets.

7.2.2   *Effect of support condition on friction*

The energy uptake in the set with bedding of two layers of PVC-membranes+grease is used as reference (E_{PVC}) as we assume that there is no or very little friction influence for this case. Thus, the friction effect for the other support conditions (E_s) is calculated according to:

Equation 4 $$\text{Friction effect (\%)} = \left(1 - \frac{E(\Delta)_{PVC}}{E(\Delta)_s} \right) \text{x} 100\%$$

where Δ is the displacement and the index s is the given support condition.

Average accumulated energy uptake for each test set versus central displacement is shown in Fig. 7.1-a, and the average accumulated friction effect according to *Equation 4* for each set is plotted in Fig. 7.1-b. Note that the curve for the condition "2xTeflon" contain only one single panel test due to logging errors for the other two panels in the set, hence the result is therefore somewhat uncertain.

It can be seen that the average friction effect for "wood" (wooden support) is substantial and that it increases with the displacement, as found also in similar tests performed earlier [10][11][12]. At final displacement of 25 mm the accumulated friction effect from wood on the energy uptake is 42%, which also is in line with the previous tests where a 35% and a 37% friction effect were found. Including the result from the present test series (42%) this means that we have found that the average friction effect at final displacement for wooden support among our three independent test sets is 38%.

The friction effect as shown in Fig. 7.1-b for wooden support is different from the other support conditions in the way that it increases with displacement. For the other supporting conditions the friction effect decreases with the displacement.

The change in the friction curves in Fig. 7.1-b becomes less with increasing displacement. Beyond 10 mm displacement the friction curves are perhaps "as expected" in the way that placing the panel directly on wooden support gives the highest friction, then comes the new rounded steel support with less friction, then one layer of Teflon (on steel support) and finally two layers of Teflon (on steel support) with least friction. Hence the following ranking with regarding the friction effect can be put up:

Wood   >   steel   >   steel + Teflon   >   steel + 2xTeflon   >   steel + 2xPVC+grease
                                                                                                                    (reference)

It is notable that for nominally identical panels the apparent average accumulated energy uptake from zero to 25 mm displacement varies from 1052 Joule (wood) to 613 Joule (2xPVC+grease) among the different sets; this is simply due to variable friction from the support. <u>The other supporting conditions give a smooth distribution of results between the two extremes.</u>

It is also notable that placing the panel directly on the new rounded steel support (35% friction) gives apparently no reduction in friction compared to earlier tests with a steel support with sharp inner edge (28% friction) [13], on the contrary.

Note that the curves in Fig. 7.1-b start at 3 mm displacement. Below 3 mm the calculation of the friction effect is very uncertain due to the very small energies involved. Friction below 3 mm displacement is therefore not included.

Table 4 gives numbers for the average energy uptake, COV and friction effect at 25 mm displacement. Table 5 gives the same data for 5 mm displacement.

Various results from the panel tests are given in APPENDIX 4, APPENDIX 5 and APPENDIX 6
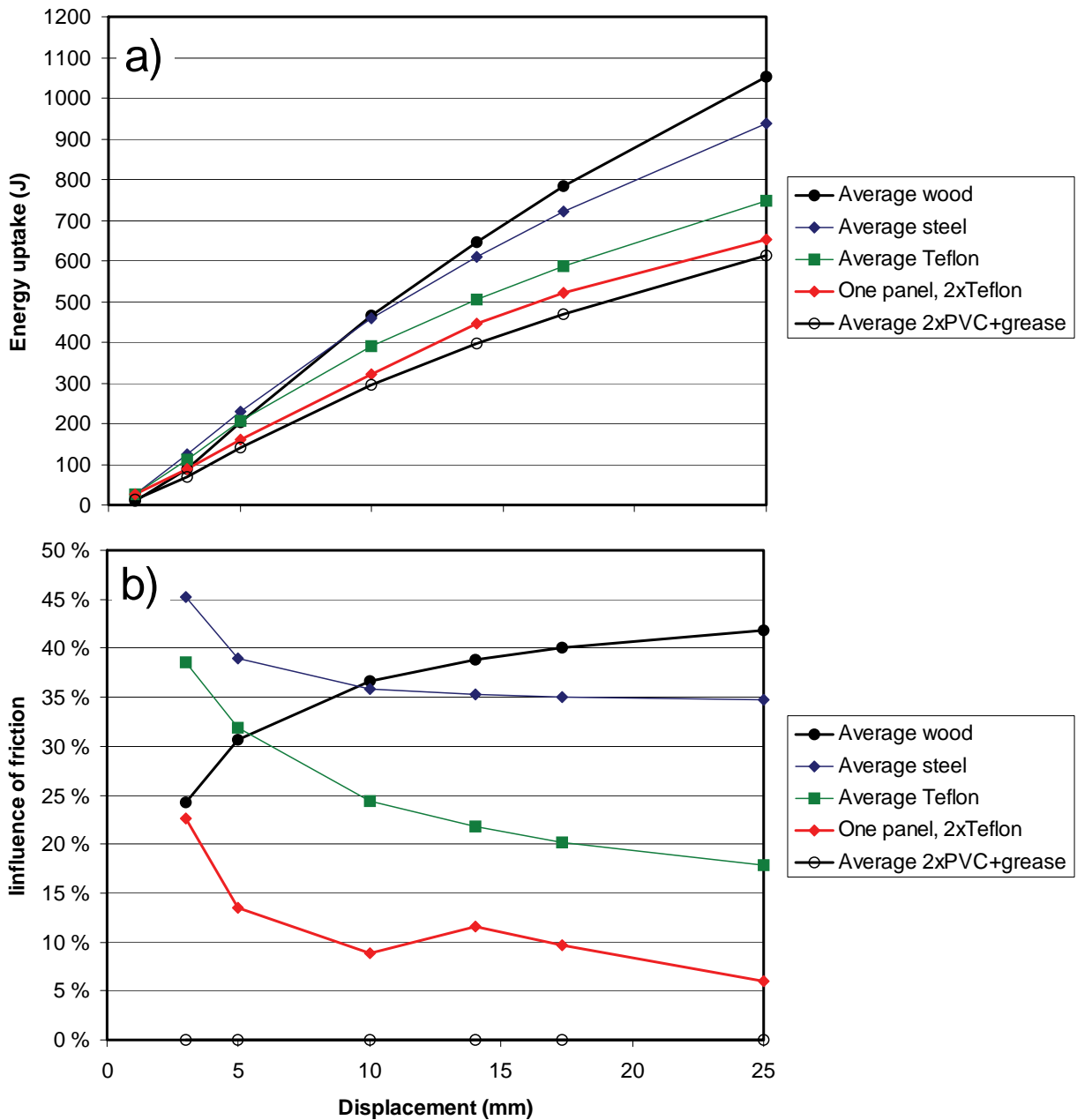
Fig. 7.1 Average apparent energy uptake vs. displacement (a). Average effect of friction in the test as compared to the set performed with 2 layers of PVC membrane+grease (b)

For four perpendicular cracks in the panel, which is quite the normal case in the present tests, the final central displacement of 25 mm corresponds to a crack opening at the panel under-side of 20 mm. The relation between displacement and crack opening is linear; hence for instance a displacement of 12.5 mm corresponds to a crack opening of 10 mm, etc.

7.3 Maximum load and residual strength

The general trend from our previous tests have been that higher friction in the test leads to both higher maximum load during the test and higher residual load at 25 mm displacement. Table 6 shows that the trend in the present tests is not systematic, but the results from the two support conditions with highest friction (panel placed directly on wood or steel) confirms the trend, especially for residual load (for which the trend also have been most pronounced in previous tests).

A negative friction effect for some cases is perhaps confusing, but is simply a result of the calculation procedure (analogue to that of *Equation 4*), and maybe the variability of the results also play a role.

Table 6: Average maximum load during the test and residual load at 25 mm displacement. And, effect of friction as compared to the support condition with 2xPVC-membrane+grease.

	Average maximum load (MPa)	Std.dev.	COV	Friction effect
Wood	61,2	3,1	5,0 %	6 %
Steel	64,8	3,7	5,7 %	11 %
Teflon	55,5	1,5	2,7 %	-4 %
2xTeflon	54,2	(only one panel)		-7 %
2xPVC+grease	57,8	3,3	5,6 %	0 %

	Average Residual load (MPa)	Std.dev.	COV	Friction effect
Wood	30,4	0,5	1,6 %	47 %
Steel	24,8	2,7	11,0 %	35 %
Teflon	17,9	0,6	3,3 %	11 %
2xTeflon	13,7	(only one panel)		-17 %
2xPVC+grease	16,0	2,4	14,9 %	0 %

7.4 Crack pattern

After end of testing, the panels were taken out of the test frame and the under-side of the panels were photographed. The photos are shown below. 16 panels developed four cracks and two panels got five cracks (one in the set "steel-no bedding" and one in the set "steel-Teflon"). One panel developed shear failure (in the set: "wood-no bedding"). One panel was not photographed.
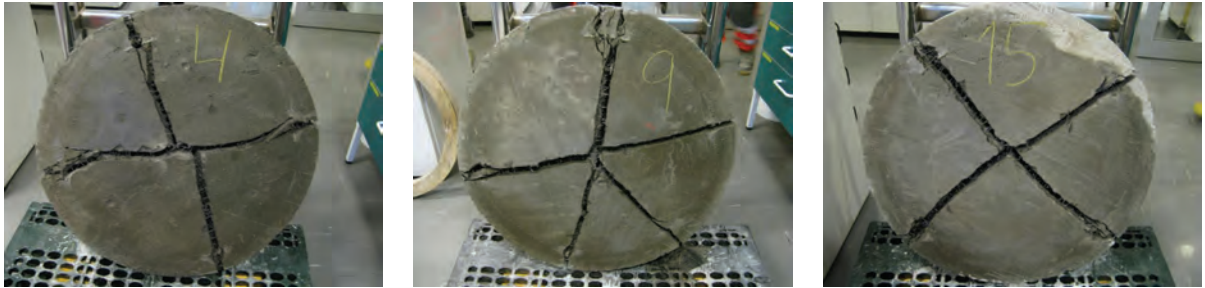
Fig. 7.2 Crack pattern, Set 3: Steel support, no bedding
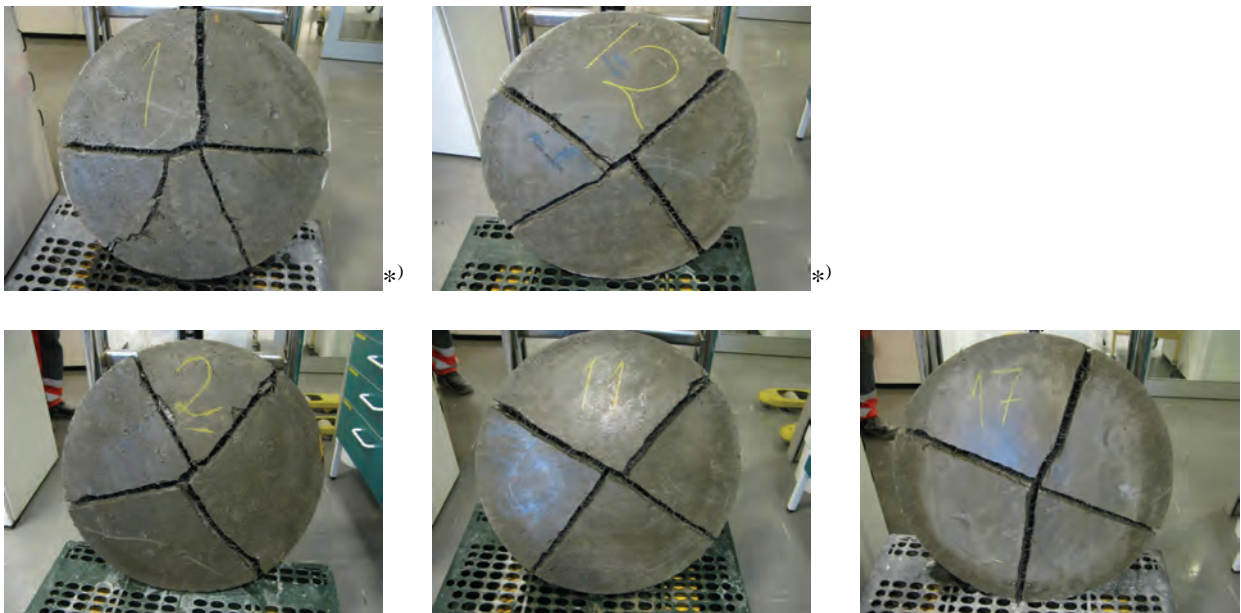
Fig. 7.3 Crack pattern, Set 1: Steel support, Teflon as bedding material. *) The data was lost due to a logging error.
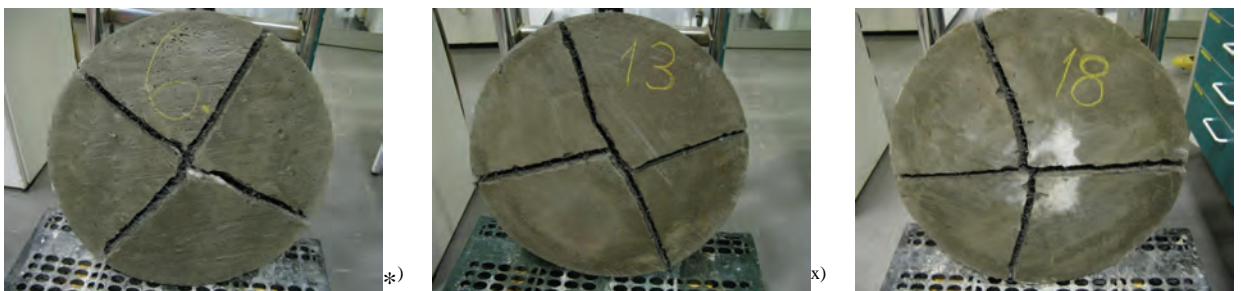
Fig. 7.4 Crack pattern, Set 5: Two layers of Teflon as bedding material. *) The data was lost due to a logging error. x) Data was lost after 10 mm displacement due to a logging error.
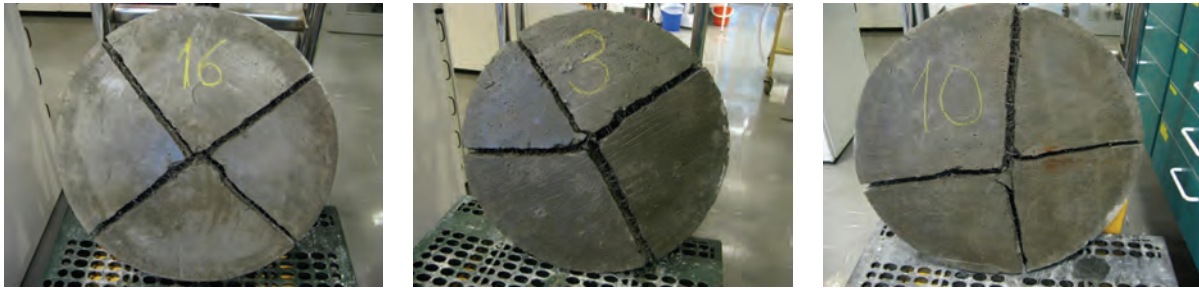
Fig. 7.5 Crack pattern, Set 2: Steel support, two layers of PVC-membrane + grease as bedding material. (the fourth panel in this set was not photographed)
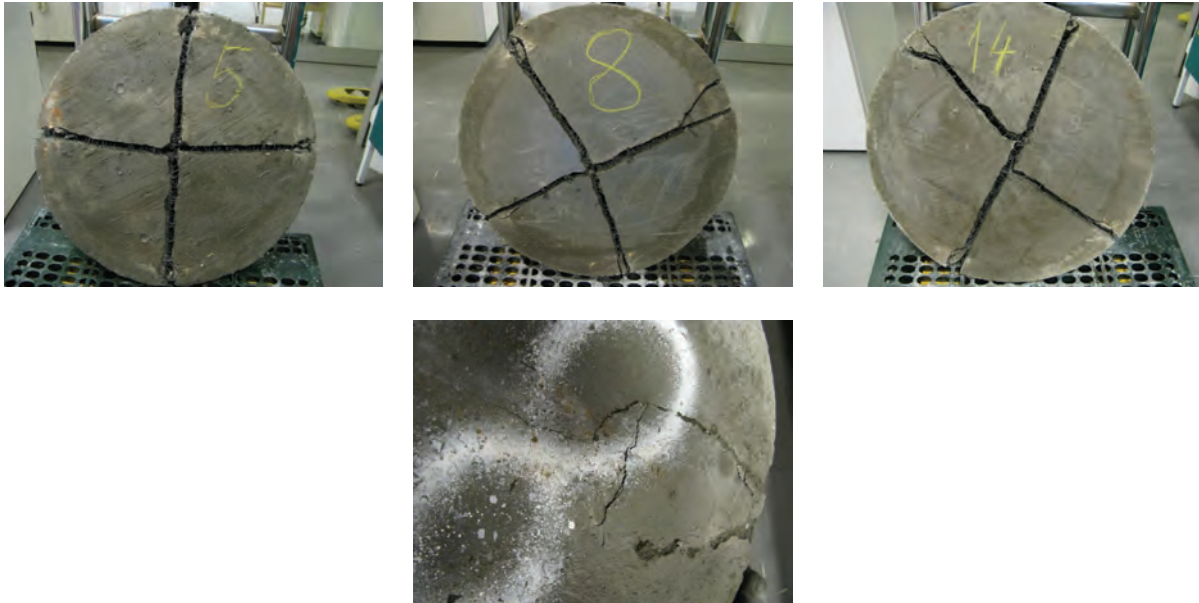
Fig. 7.6 Crack pattern, Set 4: Wooden support, no bedding. Panel 8 developed shear failure, see extra picture of the panel upper-side.

7.5 Panel-support interface

The following figures show some selected photographs that were taken, after testing, of the panel cracks in the areas that had contact with the support. In most figures we can see the footprints of friction due to the distinct point-loads that occur in the contact zones.

The "ranking" of support conditions with regard to friction was, as shown earlier, like this:

Wood > steel > steel + Teflon > steel + 2xTeflon > steel + 2xPVC+grease
(reference)

There is a clear tendency that more friction caused by the support leads to a crack-zone rather than a distinct crack. Friction apparently increases the capacity of the panel to transmit forces over the crack and more cracks tend to form around the original main crack; a sort of local strain-hardening behaviour occurs due to the reinforcing effect of friction.

Previous tests have also indicated that friction may produce extra main cracks in the panel, but such trend is not present here. It is notable, however, that one single panel of the 18 panels in total suffered shear failure; this panel was placed directly on wooden support which generated the highest friction! All pictures that were taken of the crack-zones are given in APPENDIX 7.

Fig. 7.7 Set 3: Steel support, no bedding

Fig. 7.8 Set 1: Steel support, Teflon as bedding material

Fig. 7.9 Set 5: Steel support, two layers of Teflon as bedding material

Fig. 7.10 Set 2: Steel support, two layers of PVC-membrane + grease as bedding material.
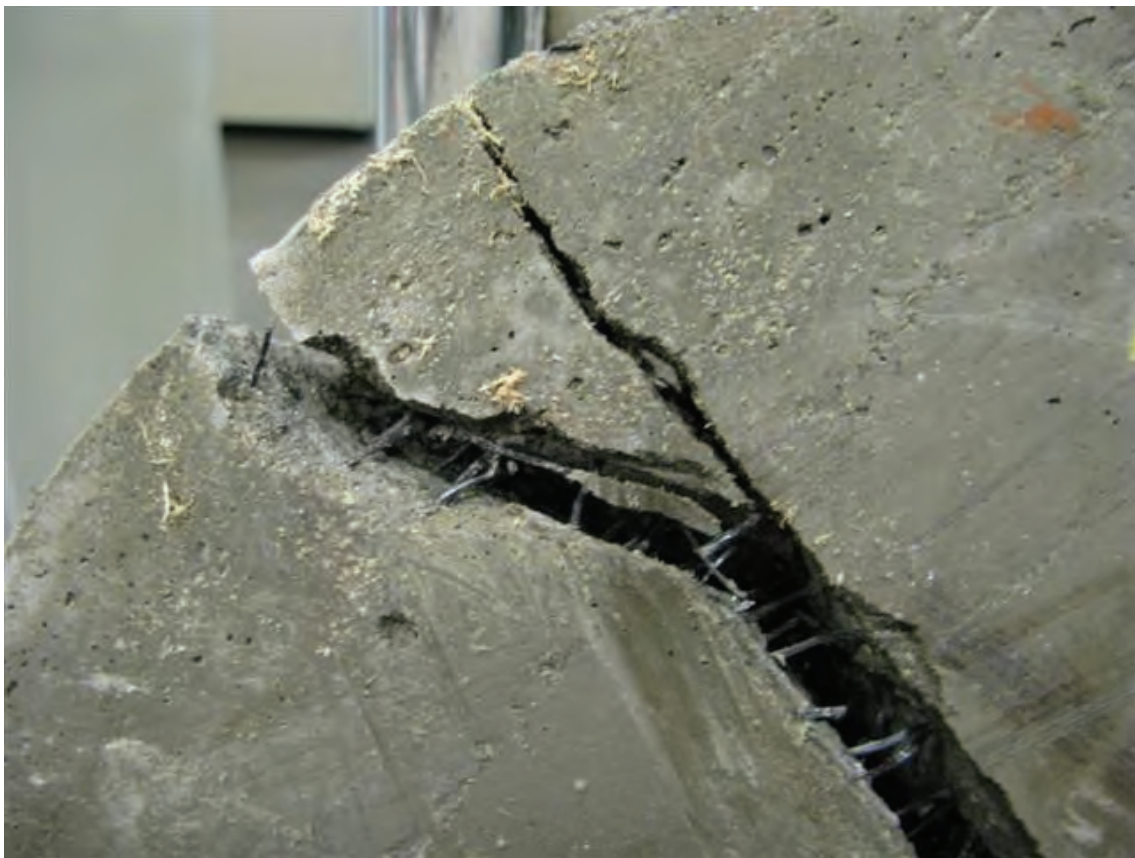
Fig. 7.11 Set 4: Wooden support, no bedding

7.6　　Wearing of the Teflon

When using one Teflon layer as bedding material, the Teflon was to a large degree broken by the sliding of the panel during testing, see examples in Fig. 7.12. This is maybe not surprising and it means that the concrete panel got semi-contact with the steel support underneath; hence we obtain a semi concrete-steel friction. This can probably explain also why the reduction of friction was no more than "semi-successful" (18% accumulated friction effect at 25 mm displacement).
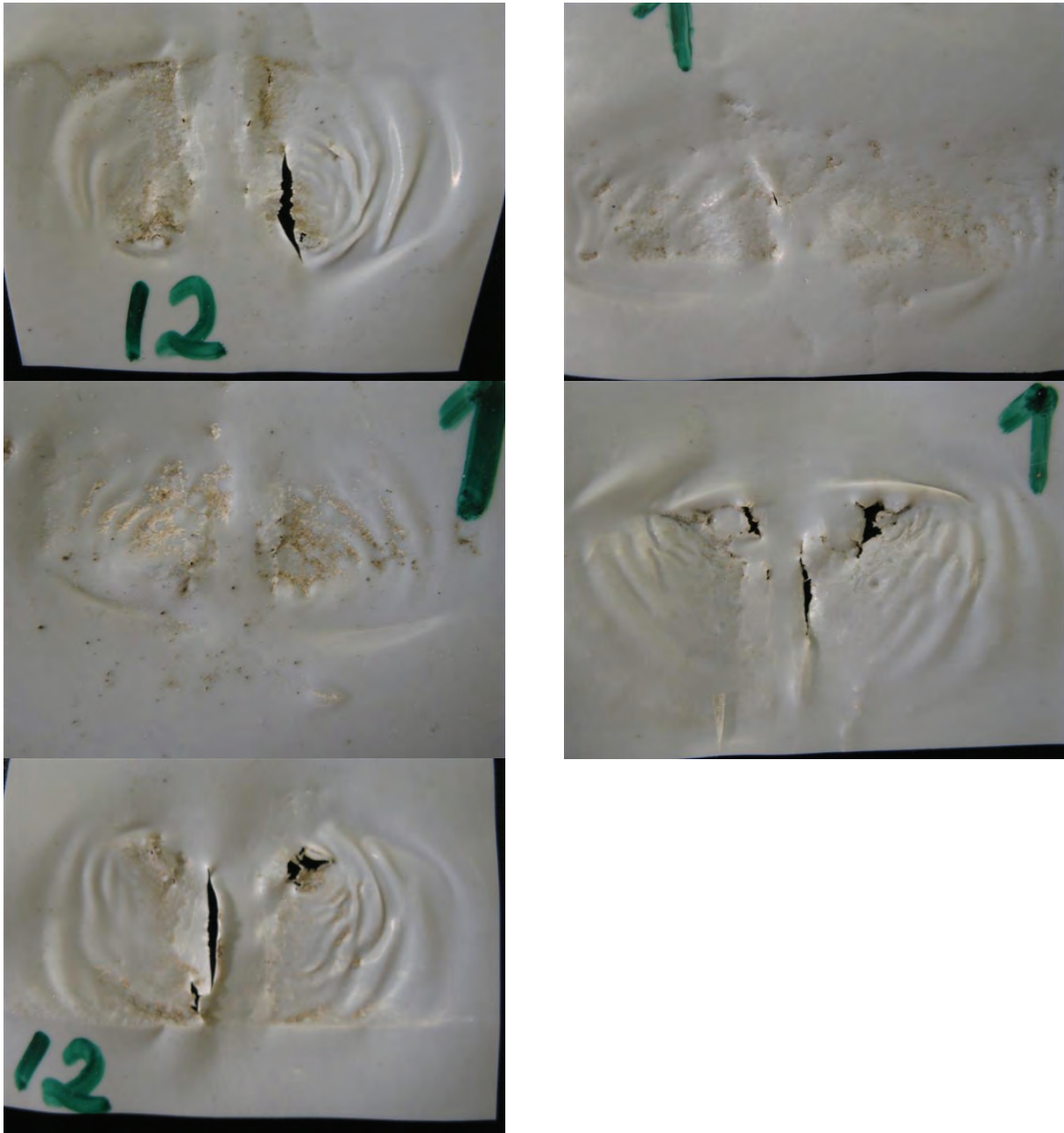
Fig. 7.12 Pictures of the Teflon at crack-zones after testing (bedding: one layer of Teflon)

When using two layers of Teflon as bedding material, the upper layer also broke to a certain extent, but the lower layer was more or less unbroken; hence we probably obtain a combination of concrete-Teflon friction, Teflon-Teflon friction, and Teflon-steel friction which may explain the further reduction of friction (6% friction effect. Note: the test set contains only one panel, as mentioned earlier).

8   Conclusions and final remarks

The panel tests made use of a new rounded continuous steel support, a continuous wooden support, and different bedding materials and -combinations; in total five different support conditions was tested. The displacement rate in the tests was 3 mm/min.

Among the four individual test sets consisting of three or four panels the results show that the average coefficient of variation for the energy uptake between zero and 25 mm displacement was 8.8%.

In panel tests with continuous support the friction occurs in two directions; tangential and radial, and the results shows that the apparent energy uptake during the test is very dependent on the support condition. Variable friction from different support materials is the cause of this dependence. The results show that friction constitutes the following portion of the accumulated apparent energy uptake in the various test sets:

Support	Bedding	Support condition	Average friction effect *(0 – 25 mm displacement)*
Wooden support	No bedding	A	42%
Rounded steel support	No bedding	B	35%
	One layer of Teflon	C	18%
	Two layers of Teflon	D	6%
	Two layers of PVC-membrane + grease	E	0% (reference)

The results confirm earlier results for support condition *A* in the way that it gives very high friction and also that the accumulated friction effect increases with the displacement. For the other support conditions the accumulated friction effect decreases with displacement. Increasing friction appears to represent a reinforcing effect which generates a local strain-hardening behaviour in the panel around the contact-zone with the support. This is seen as local multiple cracking in this zone. Support condition *E* is used as reference and the assumption is that this bedding provides no friction, but a small friction component is still likely to exist; hence the friction effects shown above are probably slightly underestimated.

Introducing Teflon as bedding material (condition *C* and *D*) has a positive effect in reducing friction, but the effect of one layer of Teflon still gives significant friction in the test. The Teflon suffered significant wearing during testing and had to be renewed in each test. A drawback with Teflon is that it makes the testing procedure more cumbersome as it gives extra work during the preparation of each test; more work naturally for two layers than for one layer. Bedding with PVC-membranes+grease (condition *E*) has shown very effective to reduce/eliminate friction and is a good reference, but it is very laborious and can hardly be used in a standard procedure.

The trend is that friction also influences the maximum load during the test as well as the residual load at the end of the test; the effect is most evident for the latter.

The new rounded steel support (condition *B*) does not give lower friction than earlier tests that used a steel support with a sharp inner edge.

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APPENDIX 1 Bedding materials, data sheets

TEFLON

Egenskapsdata
Termoplaster

Hvad er PTFE?

PTFE - Polytetrafluorethylen - bedst kendt under navnet Teflon - blev produceret af Du Pont - USA under anden verdenskrig og betragtet som strategisk materiale, fordi det brugtes i kernevåbenprogrammet. Efter krigen blev det frigivet og markedsført. I Europa er Hoechst og ICI kendte PTFE leverandører. PTFE fremstilles på grundlag af chloroform og flussyre, der i en totrinsproces først giver en monomer tetrafluorethylen, og efter polymerisationen opstår det højkrystallinske materiale PTFE. Dette er ikke en traditionel termoplast - snarere en termoelast, fordi de lange molekylkæder forhindrer, at materialet bliver plastisk ved opvarmning. Dette hindrer, at PTFE kan forarbejdes termoplastisk, dvs. ved sprøjtestøbning og extrudering.

Der er derfor udviklet andre fluorplaster, hvor det er lykkedes at bevare de fleste af PTFE's gode egenskaber, samtidig med at de er lettere forarbejdelige. Disse er:

FEP - tetrafluorethylen-hexafluorpropylen-copolymer ("Teflon FEP")
PFA - perfluoralkoxy-copolymer ("Hostaflon TFA" - "Teflon PFA")
ETFE - ethylen-tetrafluorethylen-copolymer ("Hostaflon ET" - "Tefzel")
PVDF - polyvinylidenfluorid (se særlig omtale)
PVF - polyvinylfluorid ("Tedlar" - "Dyflor")
PCTFE - polychlortrifluorethylen ("Kel-F")
ECTFE - ethylen-chlortrifluorethylen-copolymer ("Halar")
FKM - fluorelastomer ("Viten")

Anvendelsesområde

PTFE anvendes først og fremmest, hvor der er behov for et temperaturbestandigt materiale eller et materiale med exceptionel kemikalieresistens. Disse egenskaber kombineret med de velkendte slip- og friktionsegenskaber gør, at det i mekaniske konstruktioner typisk anvendes som besninger, pakninger, membraner, glideelementer etc. Desuden anvendes PTFE p.g.a. det fremragende elektriske og dielektriske egenskaber, samt temperatur- og slidbestandigheden, hvor andre materialer ikke længere slår til.

Karakteristika:

Ud over de gunstige friktionsegenskaber kendetegnes PTFE ved:
- Nærmest universel kemikaliebestandighed
- Høj termisk stabilitet
- Ringe vedhæftning (adhesion), lav friktionskoefficient
- Fremragende elektriske og dielektriske egenskaber
- Bestandighed mod spændingskorrosion
- Vejrbestandighed (UV-stråling)

Ulemperne er få, men dog væsentlige:
- Slidstyrke er ikke god
- Mekanisk styrke begrænset
- Koldflydning er udpræget

Egenskaber

Mekaniske

PTFE's ringe stivhed og relativt store tendens til koldflydning gør, at det i uforstærket tilstand kun kan anvendes ved meget lave statiske belastninger selv ved stuetemperatur.

Ved konstruktive forholdsregler som f.eks. indkapsling og ved kortere varende belastninger kan koldflydning begrænses, og man kan udnytte materialets fremragende glideegenskaber selv ved store specifikke belastninger. Tilsætning (compounding) af diverse forstærkningsmaterialer kan forbedre de mekaniske egenskaber, men det sker oftest på bekostning af nogle af de øvrige egenskaber.

Termiske

Den store termiske stabilitet gør, at PTFE kan anvendes kontinuerligt i temperaturområdet -270 til +260°C. Selv ved meget lave temperaturer bevarer PTFE sin fleksibilitet og elasticitet, og kortvarigt kan den maksimale temperatur ofte uden problemer overskrides, idet der dog må advares mod temperaturer over 300°C, hvor en langsom nedbrydning med frigivelse af spaltningsprodukter (fluorforbindelser), der er farlige, påbegyndes.

Dimensionsstabiliteten påvirkes af, at der ved 19°C forekommer en omlejring i molekylestrukturen, der medfører en volumenændring på ca. 1% og en i øvrigt relativt stor lineær termisk udvidelseskoefficient.

Elektriske

PTFE er en god elektrisk isolator; isoleringsevnen påvirkes næsten ikke ved selv længere tids ophold i vand og er indtil 150°C stort set uafhængig af temperaturen. Også de dielektriske egenskaber er fremragende og inden for meget store områder nærmest uafhængig af såvel frekvens som temperatur.

Optiske

PTFE anvendes ikke, hvor synligt lys skal transmitteres, fordi det kun ved tynde folier kan trænge igennem.

Fysiologiske

Ren PTFE (uden tilsætningsstoffer) er et fysiologisk inaktivt materiale, og der kendes ikke til negative indvirkninger ved kontakt med PTFE. PTFE kan anvendes i emner, der kommer i kontakt med føde- og medicinalvarer, idet de fleste typer opfylder kravene fra FDA og BGA.

Kemikalieresistens

Den strukturelle opbygning af PTFE med en stærk kulstof-fluorforbindelse og en næsten fuldstændig indhylning af kulstofkæden af de store fluoratomer giver PTFE sin nærmest universelle kemikalieresistens. Til trods for, at der ikke kendes stoffer, der ved temperaturer under 300°C kan opløse PTFE, angribes det af smeltede og opløste alkalimetaller, flourholdige kulbrinter og ioniserende stråling.

Spændingsrevnedannelse og -korrosion finder ikke sted.

Vejr- og UV-stabilitet

PTFE kan uden tilsætning af stabilisatorer anvendes udendørs, og selv efter lang tids påvirkning under ekstreme klimatiske forhold forekommer der ikke ændringer i materialets egenskaber.

PTFE egner sig ikke til anvendelser i forbindelse med høj-energi-bestråling.

Brand

PTFE er ikke brændbart, men ved overophedning sker der en nedbrydning af materialet under dannelse af fluor-brinte, der er en giftig luftart. Af samme årsag må der ikke ryges eller anvendes åben ild i forbindelse med for- og bearbejdning af PTFE.

Bearbejdning/Forarbejdning

Spåntagning

Der må ikke ryges i lokaler, hvor der arbejdes med PTFE.

Spåntagende bearbejdning af PTFE kan foretages på almindelige værktøjsmaskiner. Det er afgørende, at stålene er skarpe og slebet i korrekte vinkler. Nærmere herom kan findes i hæftet "Spåntagende bearbejdning af plast" fra Dufa an AS.

Plastens sejhed med henblik til spændingsudligning betyder endvidere, at man ofte kan foretages grovbearbejdning, uden at det går ud over det færdige produkts kvalitet. Endvidere skal man være opmærksom på den forholdsvis store lineære termiske udvidelseskoefficient samt krystalomlejringen, der finder sted omkring 19°C og medfører relativt store dimensionsforandringer.

På grund af dårlig varmeledning bør der køles med olieemulsion.

Termoformning

PTFE er meget vanskeligt at termoforme. Det er dog muligt at præge emner af halvfabrikata. Temperaturen skal være ca. 320°C. Værktøjet opvarmes til ca. 250°C, og der skal bruges et tryk på ca. 200 bar.

Samlemetoder

Ved montering af emner i PTFE bør man være opmærksom på, at store statiske belastninger medfører krybninger. Derfor er formsluttende forbindelser gunstigere end friktionsforbindelser og f.eks. en mangenet bedre end en feder- og notforbindelse, og en snapforbindelse ofte gunstigere end en skrueforbindelse.

Ved samling af plast med et andet materiale bør man være opmærksom på plastens væsentligt større temperaturudvidelseskoefficient. Denne gør, at der ofte skal være større spillerum for at give plads for udvidelser ved svingende temperaturer.

Limning

På grund af PTFE's store kemikalieresistens samt udprægede upolaritet egner det sig ikke uden forbehandling til limning. Ved en ætsning (foretages af leverandøren) af overfladen kan der opnås en rimelig limstyrke med f.eks. epoxybaserede limtyper.

Svejsning

På grund af den store varmebestandighed og høje smelteviskositet kan PTFE normalt ikke svejses. Ved anvendelse af specialteknikker kan tynde folier dog svejses.

Overfladebehandling

På grund af den afvisende overflade er enhver form for overfladebehandling meget kompliceret.

Halvfabrikatamuligheder

Til fremstilling af halvfabrikata af ren PTFE kan den normale extrusionsmetode ikke anvendes. Alt efter dimension og facon anvendes pressintring, hvor materialet presses i facon ved rumtemperatur og sintres efterfølgende ved ca. 375°C, eller ramextrudering, der er en kontinuerlig presse- og sintremetode.

PTFE kan leveres i plader, stænger og emner i hvid naturfarve.

PTFE kan leveres med tilsætning af glasfibre, grafit, kulstof, bronze eller andre stoffer, som kan forbedre de mekaniske egenskaber.

2

Data for PTFE

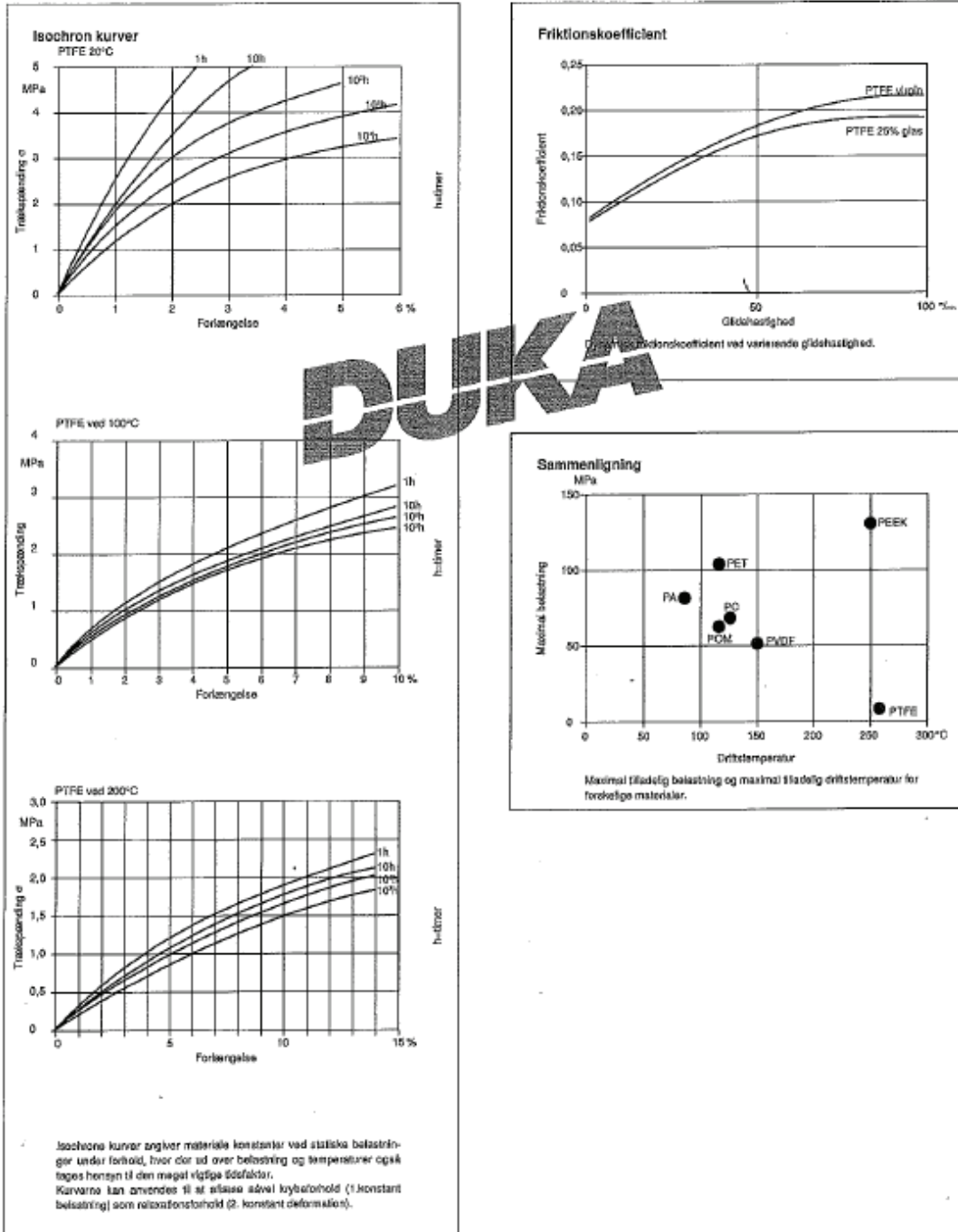| PTFE - Fysiske egenskaber	DIN	ISO	ASTM	ENHED	PTFE Virgin	PTFE 25% glas	PTFE 15% grafit	PTFE 60% bronze	PTFE 25% kul
Densitet	53479	1183	D 1457	g/cm	2,18	2,25	2,18	3,9	2,11
Vand absorption	53472/8.2	-	-	-	0	-	-	-	-
Mekaniske egenskaber									
Træk forsøg:									
trækstyrke ved svigt (støbt)	53455	R 527	D 1457	MPa	30	20	18	18	19
trækstyrke ved svigt (extruderet)	53455	R 527	D 1457	MPa	26	14	-	14	15
forlængelse ved brud (støbt)	53455	R 527	D 1457	MPa	400	340	250	260	230
forlængelse ved brud (extruderet)	53455	R 527	D 1457	MPa	400	220	-	220	140
elasticitetsmodul	53455	R 527	D 1457	MPa	750				
Trykforsøg (støberetning):									
1% offset trykstyrke	53454	604	D 695	MPa	4,3	8,2	7,3	10,3	11
Tryk - krybeforsøg (støberetning):									
deformation ved en belastning									
på 13,5 MPa efter 24 timer/23°C		-	D 621	%	14,3	7,1	8,1	6,0	6,0
på 13,5 MPa efter 24 timer/260°C		-	D 621	%	30,1	10,8	16,0	10,6	10,2
Slagstyrke:									
(20°)		180/2C	D 256	J/m	154	115	109	104	83
Kuglotrykshårdhed H132/60	53456	2039-1		MPa	32	36	35	43	41
Hårdhed Shore D			D 2240	-	60	64	64	70	69
Termiske egenskaber									
Smelte temperatur				°C	327	327	327	327	327
Varmeledningsevne	52612	-		W/m·K	0,24	0,41	0,78	0,69	0,59
Lineær termisk udvidelses-koefficient									
middelværdi 23-95°C			D 696	10⁻⁵	122	76	79	79	84
middelværdi 23-260°C		-	D 696	10⁻⁵	164	101	108	105	111
Maximal anvendelsestemperatur i luft:									
korte perioder				°C	300	300	300	300	300
kontinuerligt				°C	260	260	260	260	260
minimum anvendelses-temperatur				°C	200	200	200	200	200
Elektriske egenskaber									
Specifik gennemgangs modstand	53482	93	D 257	Ohm-cm	10¹⁸	10¹⁸	10¹⁰	10⁷-10⁸	10⁵
Overfladomodstand	53482	93	D 257	Ohm-cm	10¹⁷	10¹⁷	10⁵	10⁷-10⁸	10⁵
Dielektrisk styrke			D 3294	kV/mm	20	13			
Dielektrisk konstant:									
ved 10⁶ Hz	53483	250	D 150	-	2	2,85			
Dielektrisk tabstal tanδ:									
ved 10⁶ Hz	53483	250	D 150	-	0,0003	0,0029			

3

Data for PTFE

Dielektriske egenskaber

W/m·K

Relativ dielektricitetskonstant, PTFE (målt efter VDE0303 ved forskellige frekvenser).

Termisk dimensionsstabilitet

10⁻⁵/K⁻¹

Lineær termisk udvidelse PTFE som funktion af temperaturen.

Krybeforhold

%

Krybning ved rumtemperatur (23°C) ved en last på 13,7 MPA.

Dynamisk

Det dynamiske elasticitetsmodul E' samt den mekaniske tabsfaktor d for PTFE.

Slagstyrke

kJ/m²

Kærvslagstyrke for PTFE ved forskellige temperaturer (DIN 53 453).

Trykbelastning

MPa

Tryk-deformation for forskellige PTFE typer ved 23°C.

4

Data for PTFE

Isochron kurver
PTFE 20°C

Friktionskoefficient

Diagram over friktionskoefficient ved varierende glidehastighed.

PTFE ved 100°C

Sammenligning

Maximal tilladelig belastning og maximal tilladelig driftstemperatur for forskellige materialer.

PTFE ved 200°C

Isochrone kurver angiver materiale konstanter ved statiske belastninger under forhold, hvor der ud over belastning og temperaturer også tages hensyn til den meget vigtige tidsfaktor.
Kurverne kan anvendes til at aflæse såvel krybeforhold (1.konstant belastning) som relaxationsforhold (2. konstant deformation).

Egenskabsprofil

Randers 1992

6

PVC-membrane

Mipoplast®-0815/5, 1.50 mm

Sheet waterproofing membrane

Product Description	Mipoplast®-0815/5 is a homogenous sheet waterproofing membrane, based on polyvinylchloride (PVC-P).
Uses	■ Waterproofing of prefabricated components for small and medium-sized swimming pools ■ Pre-formed and transportable pools (i.e. children's paddling pools)
Characteristics / Advantages	■ High resistance to ageing ■ High tensile strength and elongation ■ UV stabilised ■ Hygenic and resistant to algal growth ■ Resistant to chlorinated water and common swimming pool cleaning chemicals ■ High water vapour transmission ability ■ Resistant to permanent water temperatures of +30°C ■ High dimensional stability ■ High flexibility in cold temperatures ■ Hot air and solvent weldable

Tests

Approval / Standards	Complies with DIN 16 938

Product Data

Form

Appearance / Colours	Rolled sheet membrane, unreinforced Surface: smooth Membrane thickness: 1.50 mm Colour (standard): blue (2553), other colours available on request
Packaging	Roll size: 1.30 m (roll width) x 25.00 m (roll length) Unit weight: 1.84 kg/m²

Storage

Storage Conditions / Shelf-Life	Rolls must be stored in their original package, in horizontal position and under cool and dry conditions. They must be protected from direct sunlight, rain, snow and ice etc.

Construction

Technical Data		
Chemical Base	Plasticized polyvinylchloride (PVC-P)	
Thickness	0.80 mm	(DIN 53353)
Water Vapour Diffusion Resistance	< 20'000 µ	(DIN 53122)

Mechanical / Physical Properties		
Tensile Strength	Longitudinal and transversal: > 17.00 N/mm²	(DIN 53 455)
Elongation	Longitudinal and transversal: > 300%	(DIN 53 455)
Seam Strength	Cracks occur next to the seam.	(DIN 16726)
Behaviour under Hydrostatic Pressure	Watertight at 4 bar over 72 hours.	(DIN 16726)
Puncture Resistance	Watertight at a drop height of 300 mm.	(DIN 16726) (drop-weight of 500 gms)
Dimensional Change after Storage at +80°C	< 1.50%	(DIN 53377)
Behaviour when Folding in Cold	No cracks at -35°C.	(DIN 53361)

Resistance		
Appearance after Storage in Heat	No blistering, cracks or capilaries.	(DIN 53377)

System Information

System Structure	Ancillary Products:
	- Sika®-Trocal® PVC - laminated metal sheets Type WB for fixing pieces.
	- Sika®-Trocal® PVC - solvent for cold welding.
	- Sika®-Trocal® PVC - solution (Type WB), for seam sealing.

Application Details	
Substrate Quality	Clean and dry, homogeneous, free from oils and grease, dust and loose or friable particles.

Application Conditions / Limitations	
Substrate Temperature	0°C min. / +35°C max.
Ambient Temperature	+5°C min. / +35°C max.
Compatibility	Suitable Substrates: Concrete, mortar, galvanised steel, aluminium.
	Non-Suitable Substrates: Impregnated wood, high density Polyethylene and rigid PVC, requires a separation layer of geotextile.

2   Mipoplast®-0010/0, 1.00 mm   273

Construction

Application Instructions	
Application Method / Tools	This product is suitable for factory welded waterproofing of prefabricated swimming pool components.
	Membrane installation and welding procedures are developed according to the individual production specifications of pool components.
Notes on Application / Limitations	This product is not suitable for normal membrane installation works on site
Value Base	All technical data stated in this Product Data Sheet are based on laboratory tests. Actual measured data may vary due to circumstances beyond our control.
Local Restrictions	Please note that as a result of specific local regulations the performance of this product may vary from country to country. Please consult the local Product Data Sheet for the exact description of the application fields.
Health and Safety Information	For information and advice on the safe handling, storage and disposal of chemical products, users shall refer to the most recent Material Safety Data Sheet containing physical, ecological, toxicological and other safety-related data.
Legal Notes	The information, and, in particular, the recommendations relating to the application and end-use of Sika products, are given in good faith based on Sika's current knowledge and experience of the products when properly stored, handled and applied under normal conditions in accordance with Sika's recommendations. In practice, the differences in materials, substrates and actual site conditions are such that no warranty in respect of merchantability or of fitness for a particular purpose, nor any liability arising out of any legal relationship whatsoever, can be inferred either from this information, or from any written recommendations, or from any other advice offered. The user of the product must test the product's suitability for the intended application and purpose. Sika reserves the right to change the properties of its products. The proprietary rights of third parties must be observed. All orders are accepted subject to our current terms of sale and delivery. Users must always refer to the most recent issue of the local Product Data Sheet for the product concerned, copies of which will be supplied on request.
	It may be necessary to adapt the above disclaimer to specific local laws and regulations. Any changes to this disclaimer may only be implemented with permission of Sika® Corporate Legal in Baar.

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3

Mbbplast®-0010G, 1.50 min   5/1
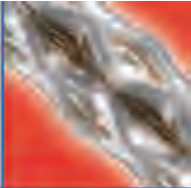
APPENDIX 2   Fibre, product data sheet

Product Data Sheet

BarChip
Synthetic Reinforcing Fibre

Product Name

SHOGUN

epc   Elasto Plastic Concrete
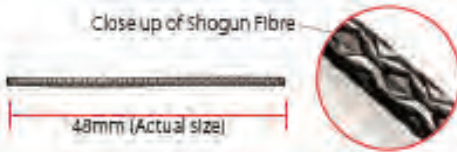
Description

Barchip "Shogun" is a Structural Synthetic fibre reinforcement added to concrete and shotcrete to replace welded wire reinforcing mesh and steel fibres.

Close up of shogun Fibre

48mm (Actual size)

Product Features

Characteristics	Material Property
Base Resin	Polyolefin
Length	48mm
Tensile Strength	550 MPa
Surface Texture	Continuously embossed
No. fibres per kg	>35,000
Specific Gravity	0,90-0,92
Youngs Modulus	10 GPa
Melting Point	150-165°C
Ignition Point	Over 450°

Benefits

- Flexural toughness equal to steel
- Long term durability – corrosion free
- Safer and lighter to handle than steel
- Reduced fire damage – anti-spalling
- Reduced wear on concrete pumps and hoses

Dosage

Barchip "Shogun" fibre can be dosed between 2 to 20 kg/m³ depending on project requirements. Typical dose rates fall in the range of 3 kg/m³ for concrete floors and 5 kg/m³ for shotcrete applications in normal ground conditions. Please ask your representative for assistance in determining fibre addition rates.

Mixing

Barchip "Shogun" fibre is best added to the batching process following the instructions detailed on EPC's "Technical Procedure: Batching and Mixing" information sheet. Barchip is packaged in a water soluble paper bag. It is recommended that the bag and contents are added to an empty agitator prior to loading other materials. Barchip disperses uniformly following 5 minutes of mixing. Dose rates in the range of 7 kg/m³ may reduce slump by approximately 20mm.

Pumping

Barchip "Shogun" fiber can be pumped through 50mm rubber hoses without difficulty. Precaution should be taken to ensure the fibres can pass freely through the pump hopper grate.

Handling and Storage

- 5 kg degradable paper bag.
- Bulk bags available on request.
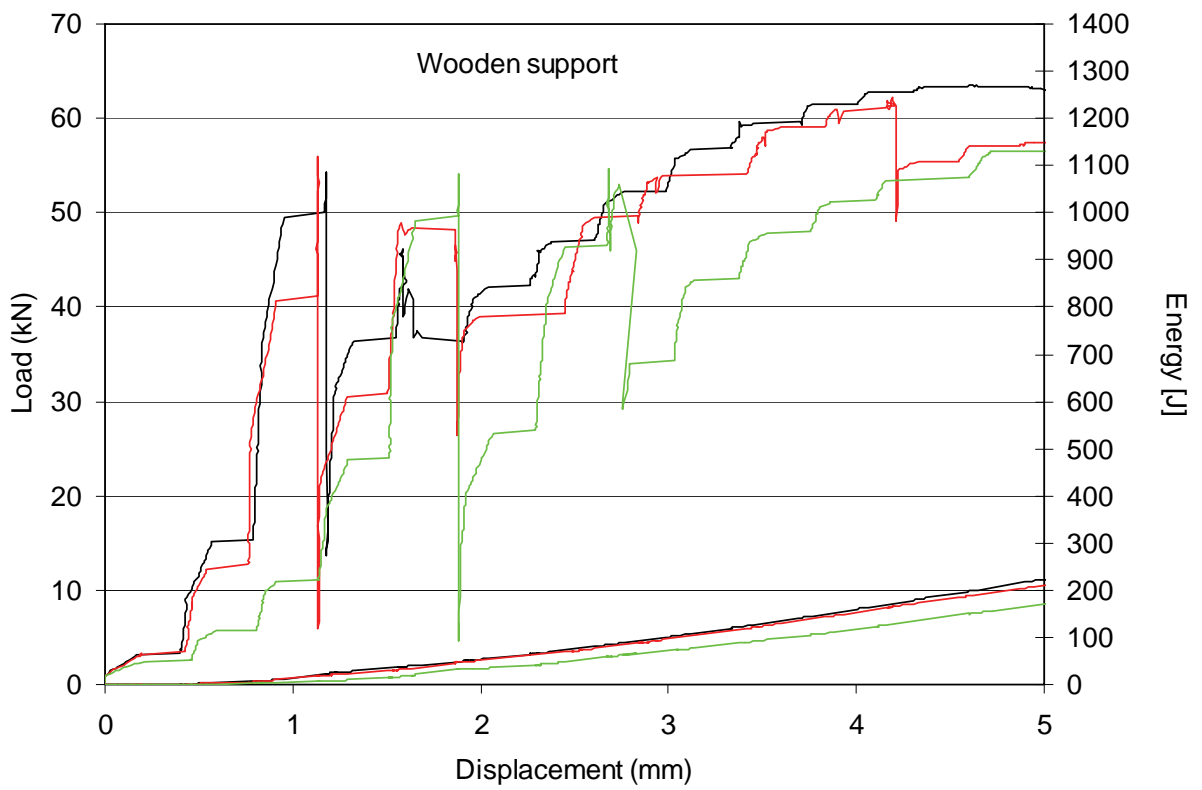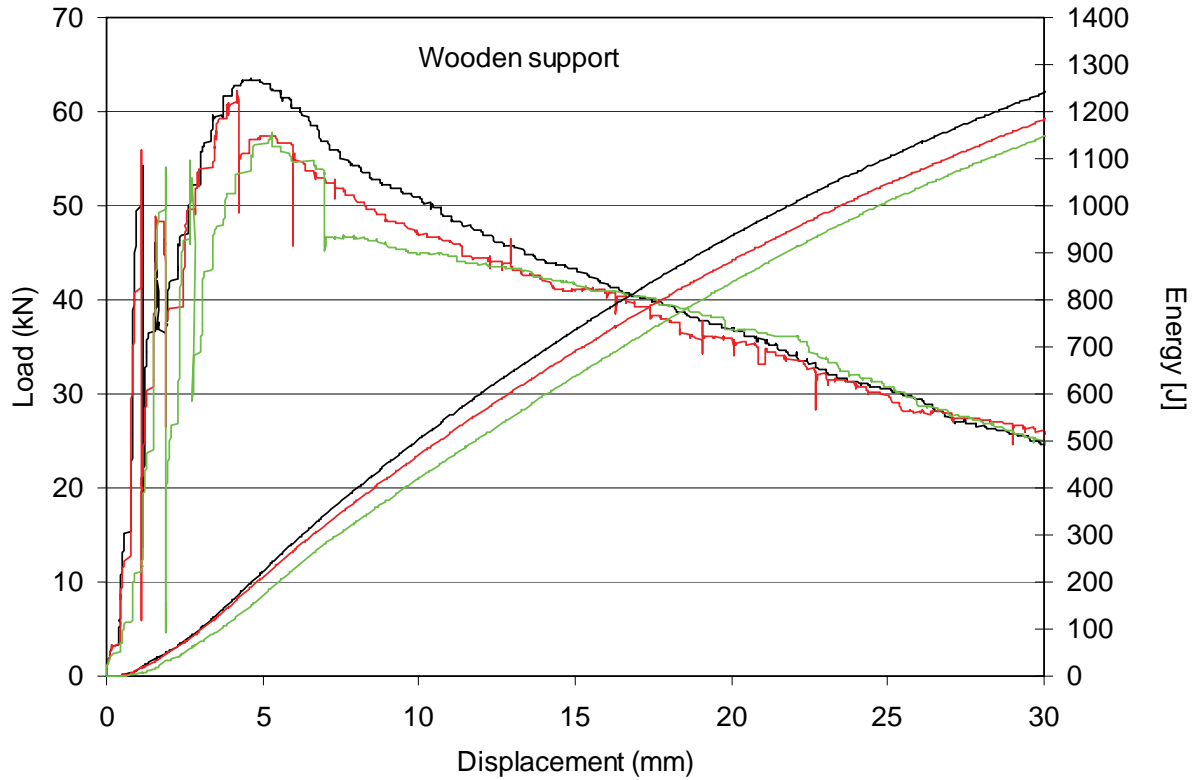
Store protected from the weather.

For safety please refer to EPC's Material Safety Data Sheet.

APPENDIX 3 Measurements of panel thickness

All values in mm.

|													Average	Std.dev.	COV
Panel 1	101,9	102,8	102,9	103,8	102,4	103,2	101,2	102,4	102,7	99,9	100,6	103,2	102,3	1,2	1,1 %
Panel 2	103,5	104,2	104,2	105,2	103,9	103,6	104,4	104,7	103,4	104,1	104,0	104,7	104,2	0,5	0,5 %
Panel 3	98,5	99,5	100,1	97,7	97,1	98,6	101,3	102,3	101,2	100,8	100,3	101,3	99,9	1,6	1,6 %
Panel 4	99,1	102,8	104,9	101,9	103,1	104,0	98,0	101,1	104,2	103,3	102,7	99,4	102,0	2,2	2,2 %
Panel 5	103,2	103,6	103,1	104,3	104,3	102,4	103,2	103,0	102,5	102,4	103,2	102,9	103,2	0,6	0,6 %
Panel 6	100,7	100,5	100,4	99,6	101,5	103,1	104,0	103,5	103,6	105,9	105,5	105,1	102,8	2,2	2,1 %
Panel 7	100,9	100,2	99,7	100,5	99,7	101,6	103,8	100,7	100,4	99,9	104,5	102,4	101,2	1,6	1,6 %
Panel 8	104,3	105,9	102,0	105,7	103,5	101,3	104,3	101,5	99,8	99,7	100,7	102,5	102,6	2,1	2,1 %
Panel 9	106,9	105,8	103,8	106,0	104,4	107,9	101,4	102,1	103,2	106,5	103,9	103,2	104,6	2,0	1,9 %
Panel 10	103,0	102,6	103,0	103,4	102,2	101,7	100,3	99,5	99,8	100,3	101,5	101,2	101,5	1,3	1,3 %
Panel 11	106,7	105,4	104,4	101,3	102,4	106,9	98,9	102,8	104,8	105,3	101,8	99,1	103,3	2,7	2,6 %
Panel 12	106,7	106,9	109,2	105,5	105,7	106,4	112,5	113,8	113,0	108,4	111,2	107,6	108,9	3,0	2,7 %
Panel 13	100,6	105,3	106,8	95,3	95,7	100,7	95,4	96,2	96,3	98,2	96,4	94,3	98,4	4,1	4,2 %
Panel 14	102,6	100,4	99,7	102,6	102,3	100,6	101,1	101,1	100,9	101,6	103,4	102,3	101,6	1,1	1,1 %
Panel 15	106,4	104,0	100,7	100,1	103,5	107,5	100,2	98,0	98,6	98,6	100,1	99,8	101,5	3,1	3,1 %
Panel 16	104,2	102,4	101,8	100,9	99,6	101,1	103,0	102,6	101,4	102,4	101,5	104,2	102,1	1,3	1,3 %
Panel 17	100,1	101,6	102,0	100,8	99,2	99,2	101,5	98,4	97,6	100,0	96,8	96,8	99,5	1,8	1,8 %
Panel 18	96,9	97,6	99,0	97,0	96,5	96,3	103,0	102,3	100,4	102,8	101,7	105,6	99,9	3,1	3,1 %

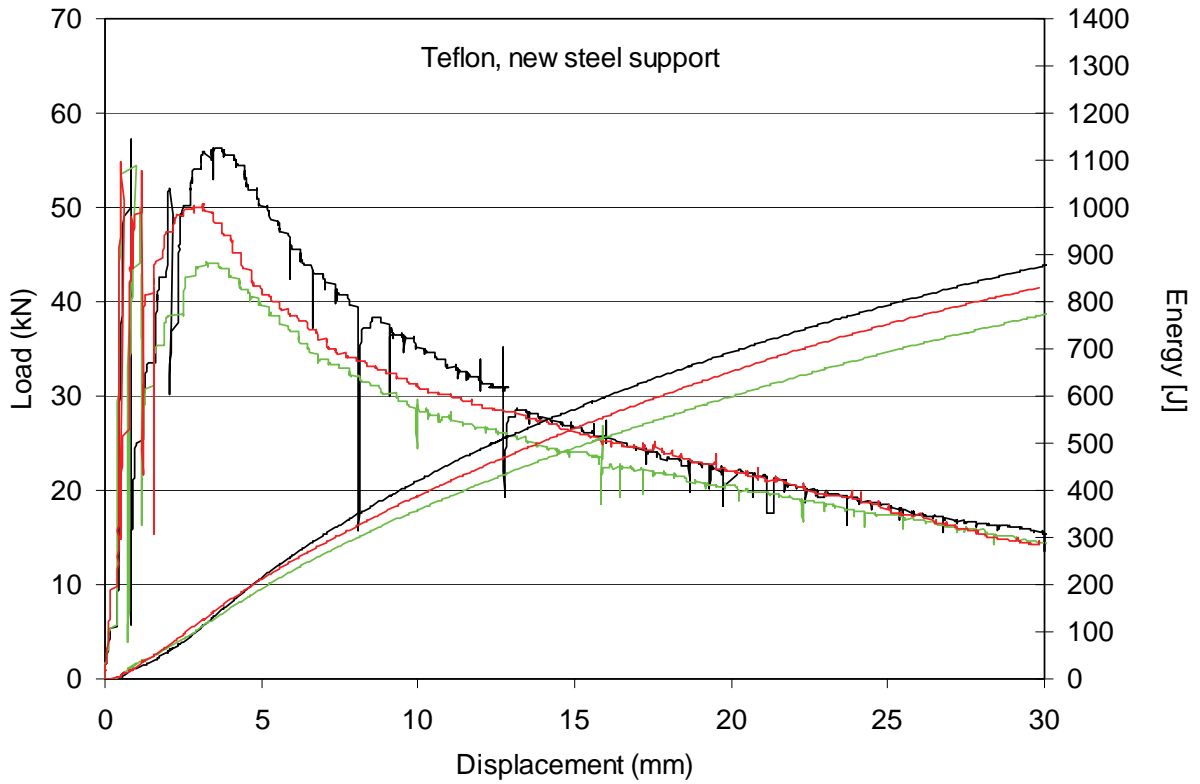# APPENDIX 4   Plots of singles results, set by set

<u>Directly on wooden support</u>
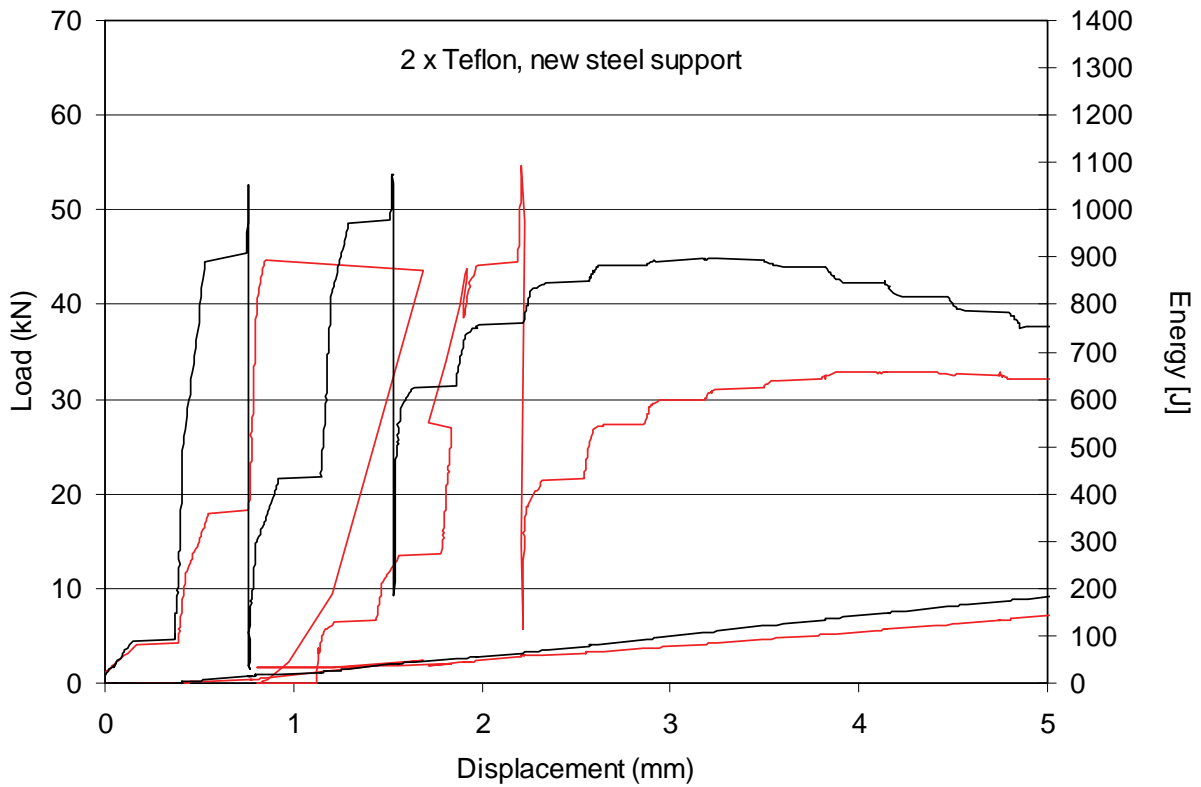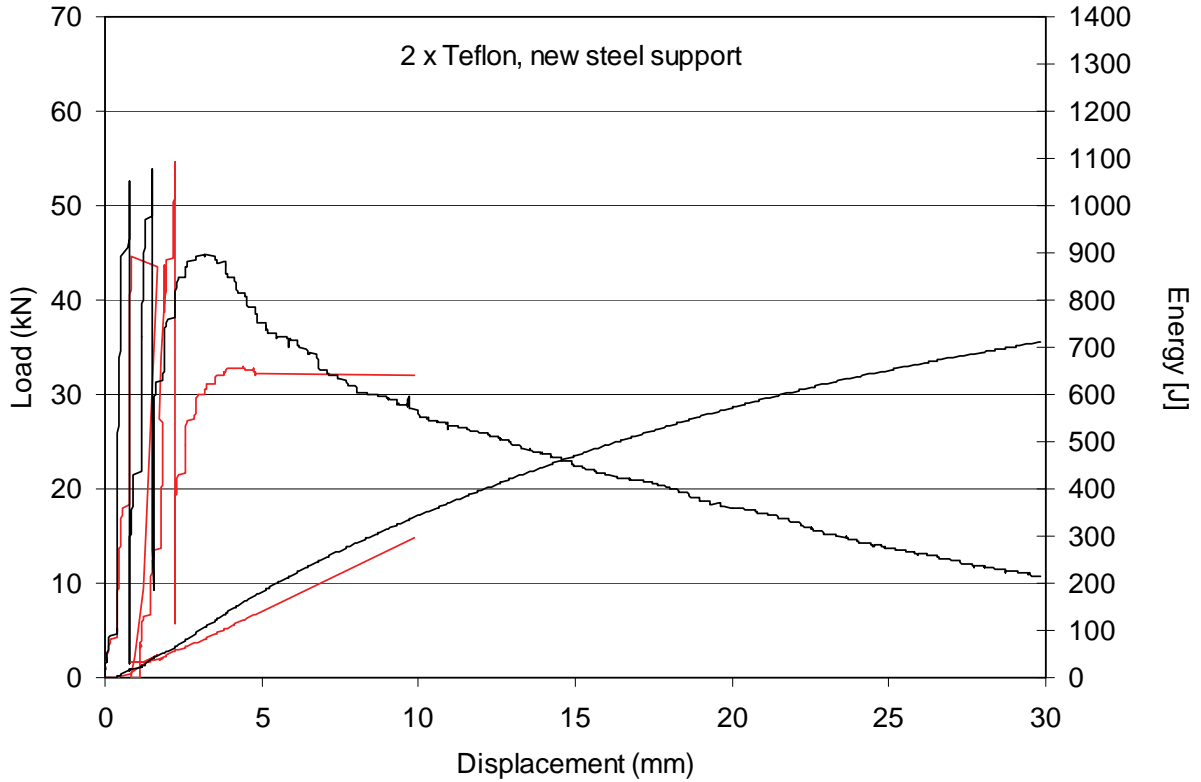
Directly on rounded steel support
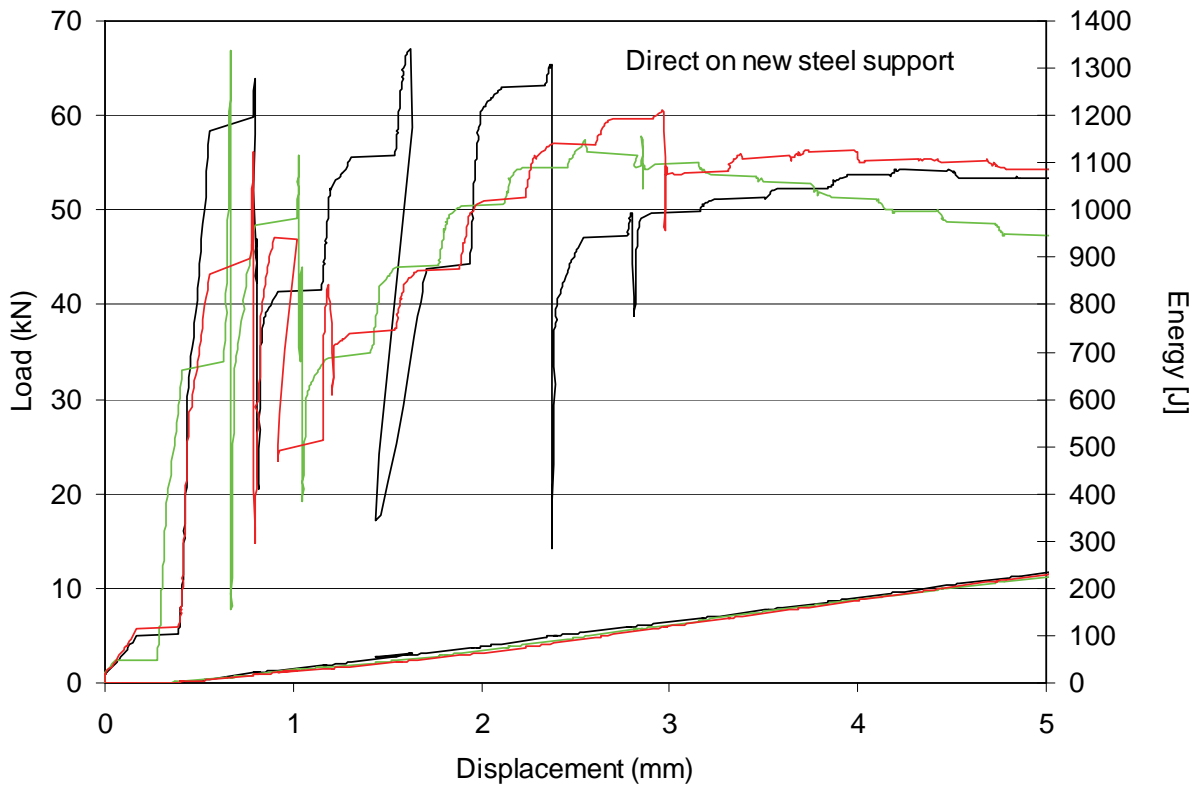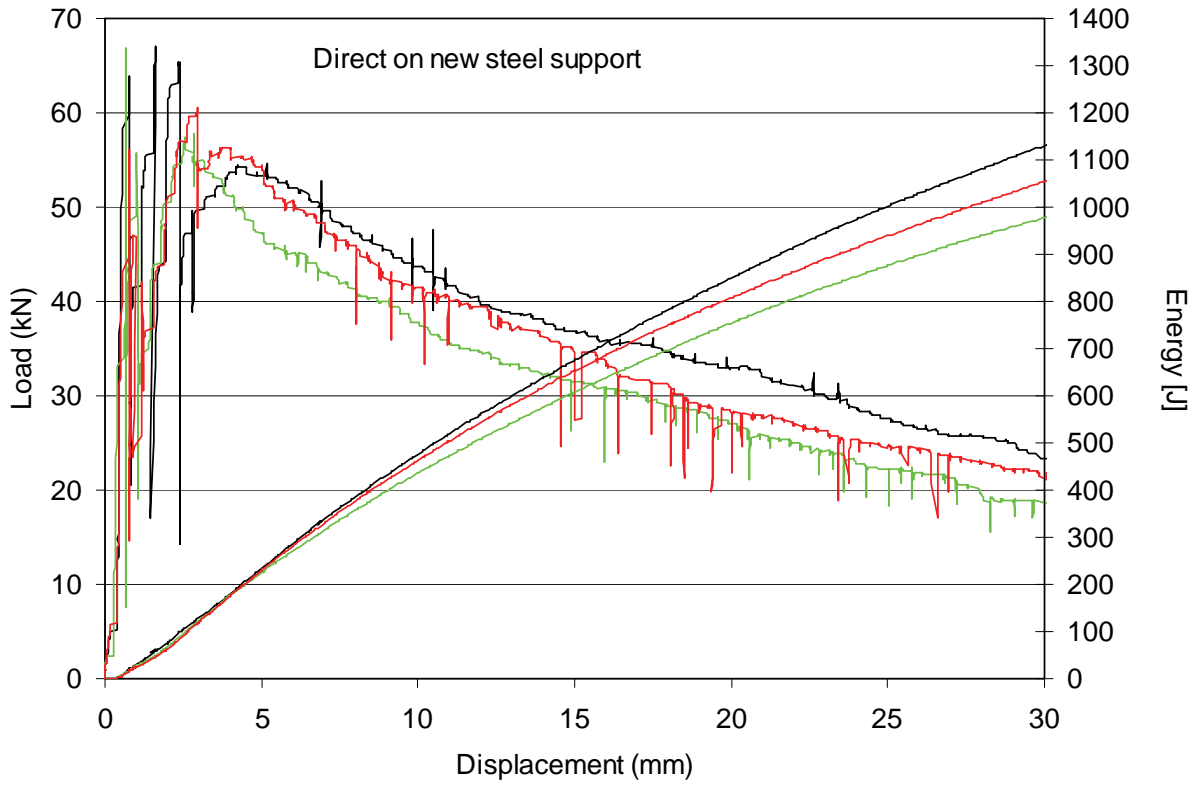
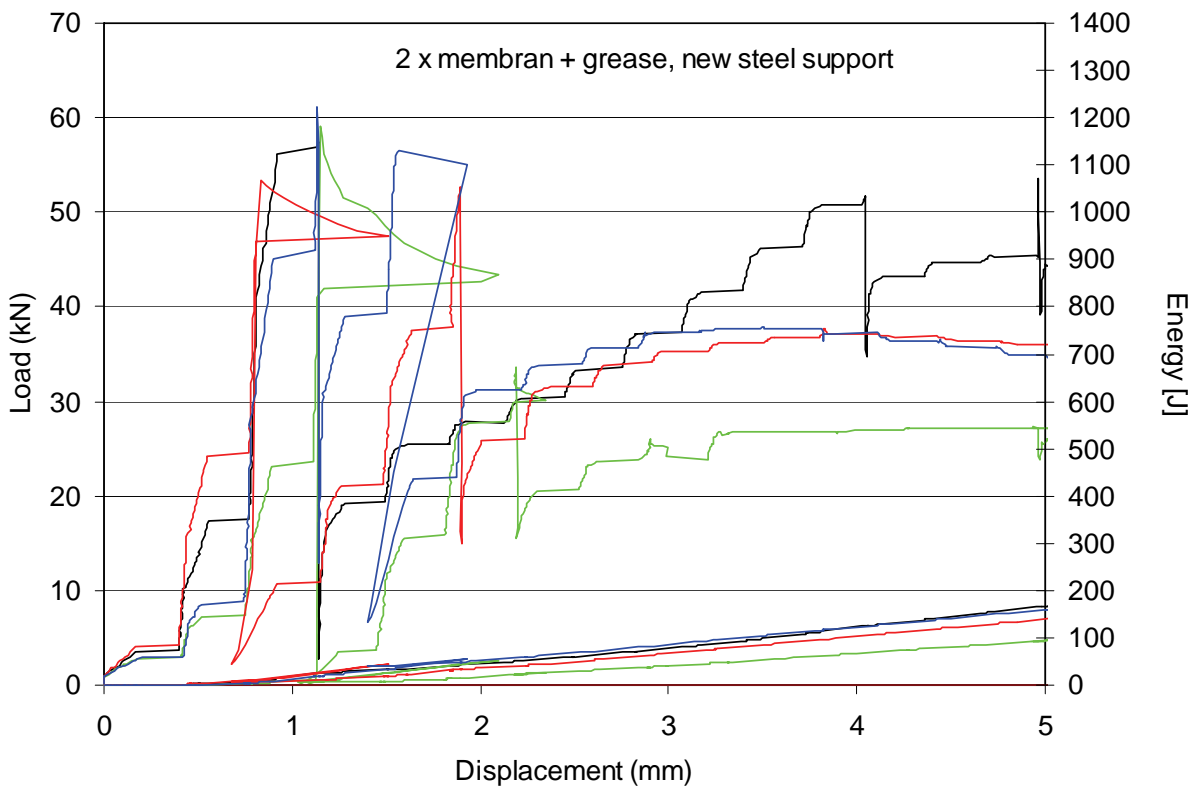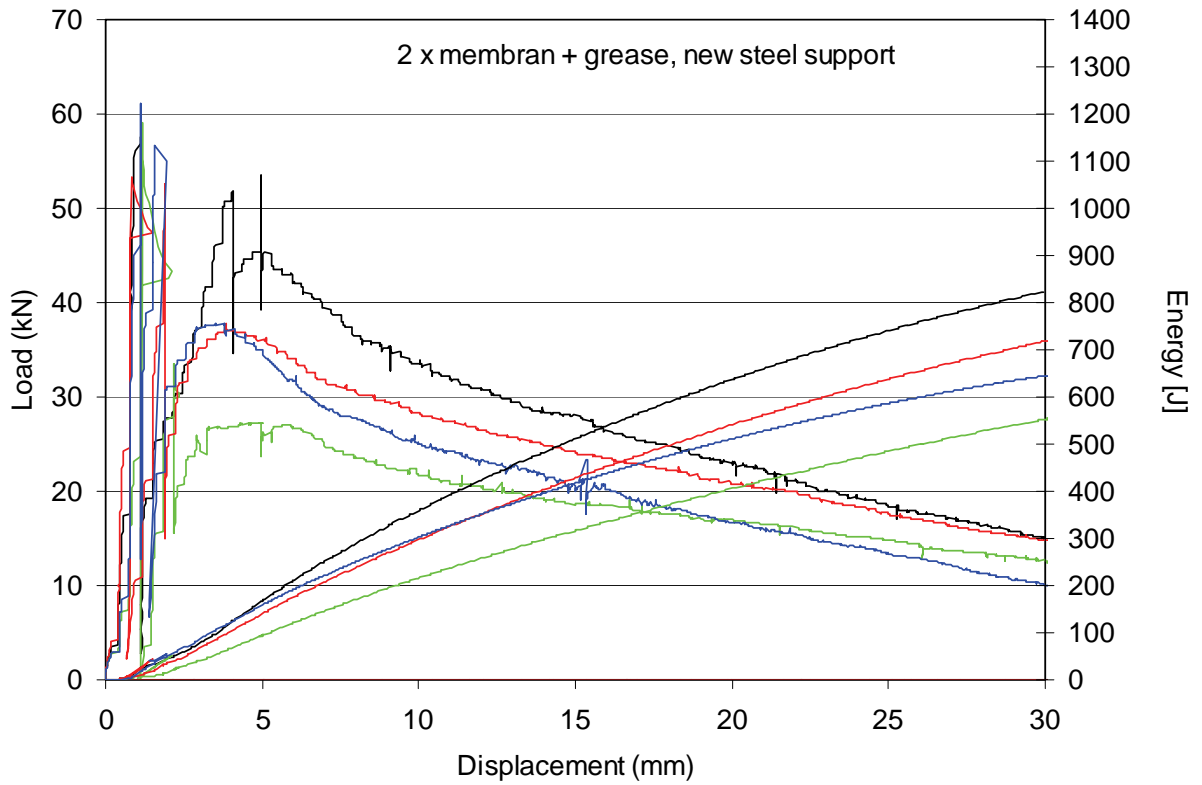## Rounded steel support + one layer of Teflon
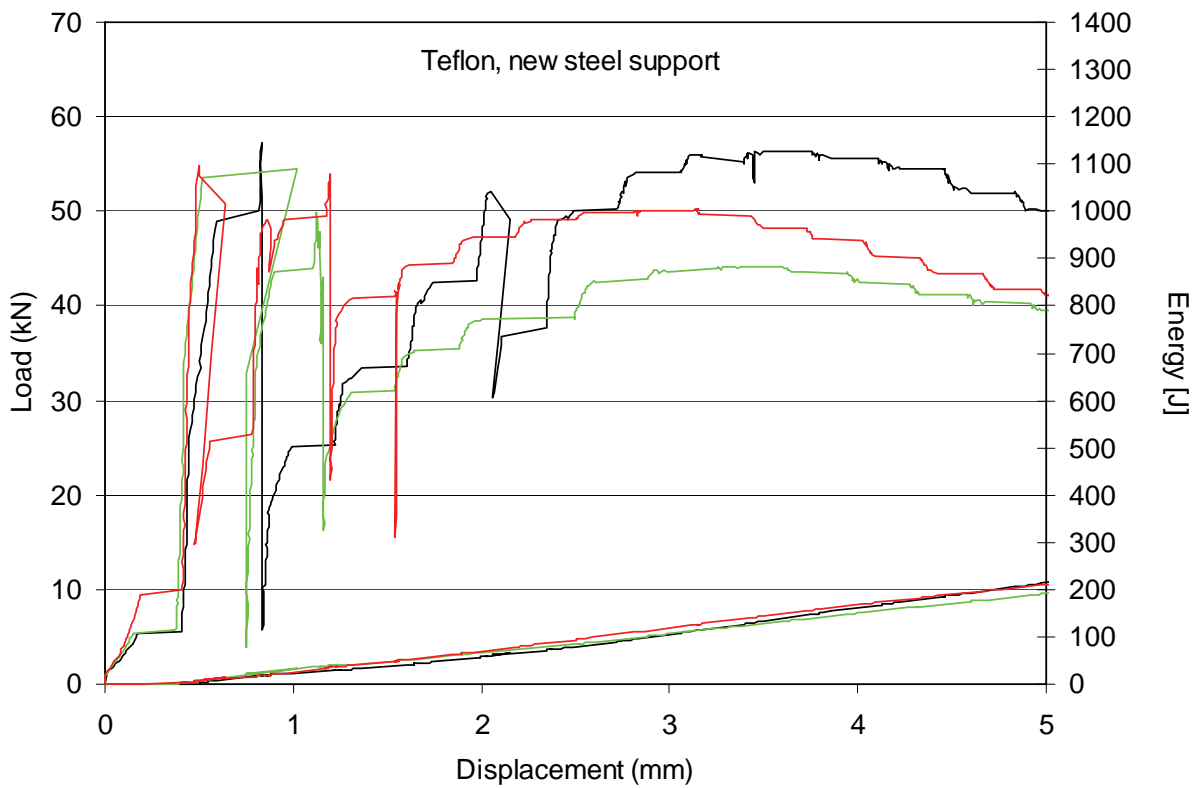
Rounded steel support + two layers of Teflon

- Panel 6: Data lost completely
- Panel 13: Data lost after 10 mm displacement
- Panel 18: Ok

Rounded steel support + two layers of PVC and grease

APPENDIX 5   Data: single results, standard deviation and COV

Displacement [mm]	Panel 5 Wood	Panel 8 Wood	Panel 14 Wood	Average wood	Std.dev.	COV
1,0	14,8	13,4	4,8	11	5,4	49,2 %
3,0	100,9	96,1	71,6	90	15,7	17,6 %
5,0	222,9	210,4	171,9	202	26,6	13,2 %
10,0	503,7	470,3	420,5	465	41,9	9,0 %
14,0	692,6	648,7	595,9	646	48,4	7,5 %
17,3	832,2	783,4	732,3	783	50,0	6,4 %
25,0	1102,5	1046,1	1008,4	1052	47,4	4,5 %

Displacement [mm]	Panel 4 Rounded steel support	Panel 9 Rounded steel support	Panel 15 Rounded steel support	Average steel	Std.dev.	COV
1,0	24,9	29,5	27,2	27	2,3	8,5 %
3,0	119,7	128,6	122,9	124	4,5	3,7 %
5,0	229,9	234,0	225,1	230	4,4	1,9 %
10,0	463,1	477,0	436,5	459	20,6	4,5 %
14,0	618,5	638,2	574,9	611	32,4	5,3 %
17,3	728,8	758,6	677,7	722	40,9	5,7 %
25,0	939,5	1002,4	876,0	939	63,2	6,7 %

Displacement [mm]	Panel 2 Teflon	Panel 11 Teflon	Panel 17 Teflon	Average Teflon	Std.dev.	COV
1,0	22,9	31,3	25,9	27	4,2	15,8 %
3,0	105,5	106,5	119,0	110	7,5	6,8 %
5,0	214,3	191,5	211,2	206	12,3	6,0 %
10,0	421,0	358,7	388,1	389	31,2	8,0 %
14,0	545,7	465,3	504,4	505	40,2	8,0 %
17,3	631,6	542,4	589,4	588	44,6	7,6 %
25,0	793,0	693,1	752,5	746	50,2	6,7 %

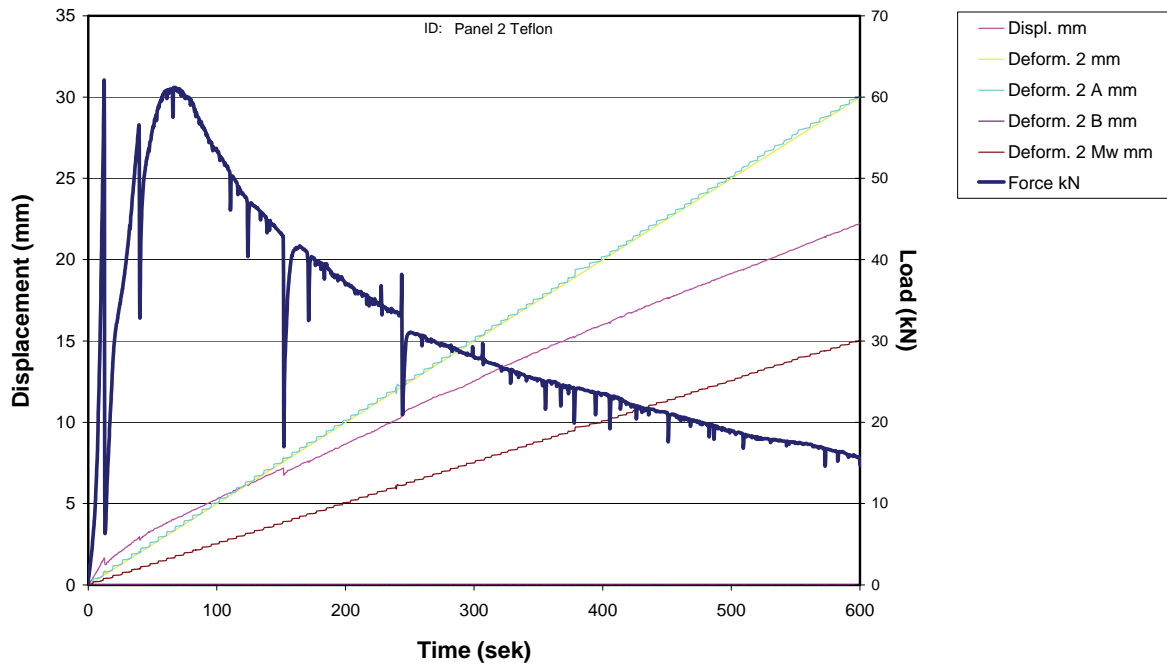| Displacement [mm]	Panel 13 Two layers of Teflon	Panel 18 Two layers of Teflon	Panel 6 Data lost	One panel, 2xTeflon
1,0	33,2	20,6		27
3,0	77,0	98,3		88
5,0	141,1	182,5		162
10,0	301,7	343,9		323
14,0		447,1		447
17,3		520,0		520
25,0		651,5		651

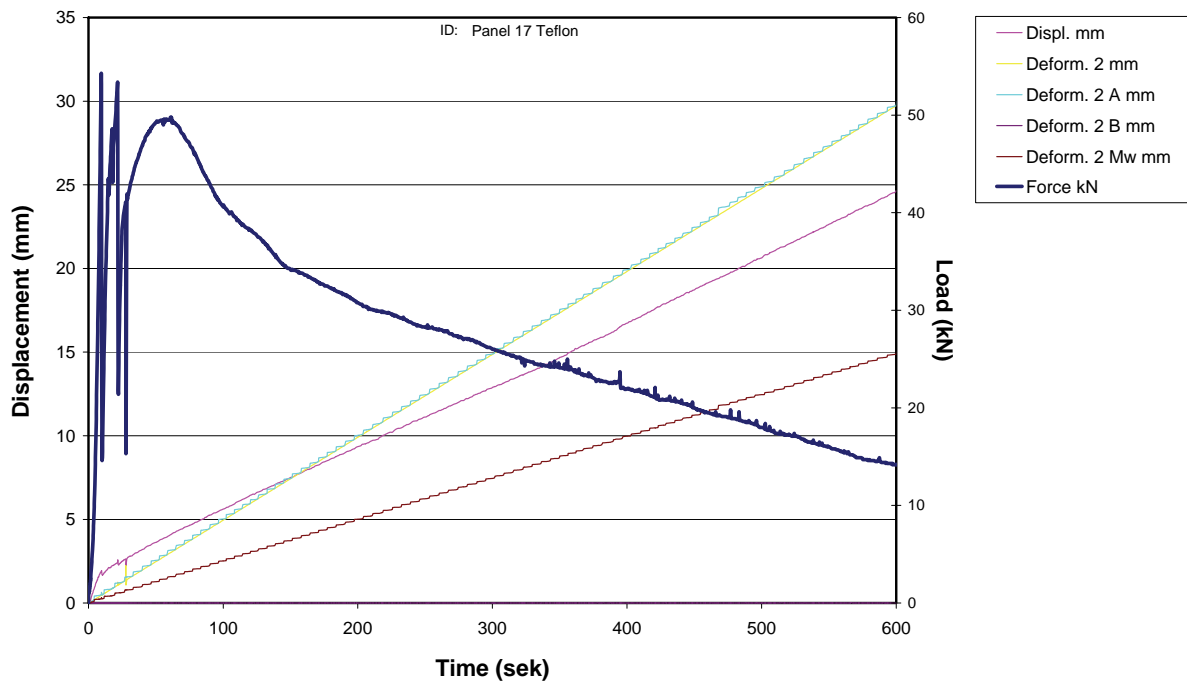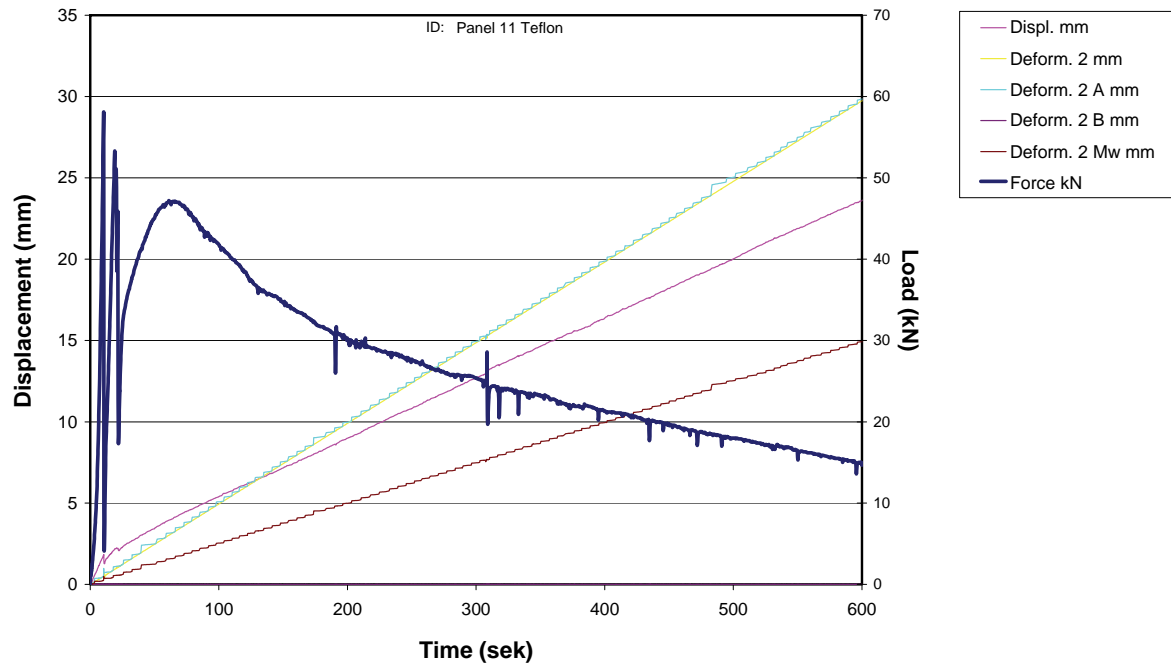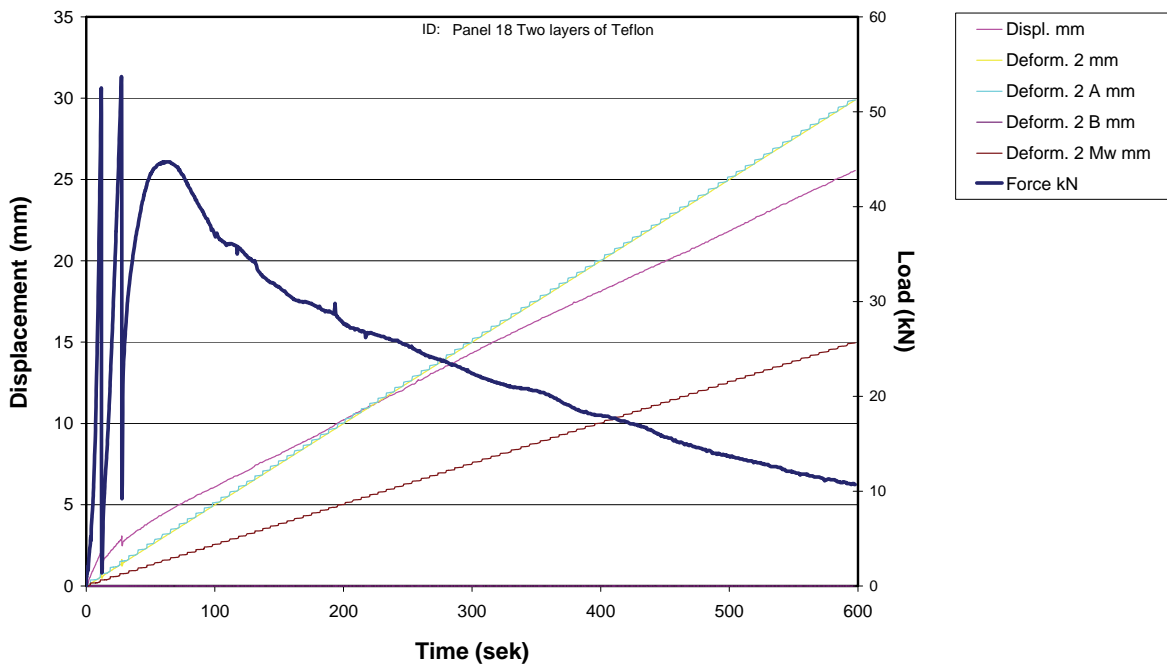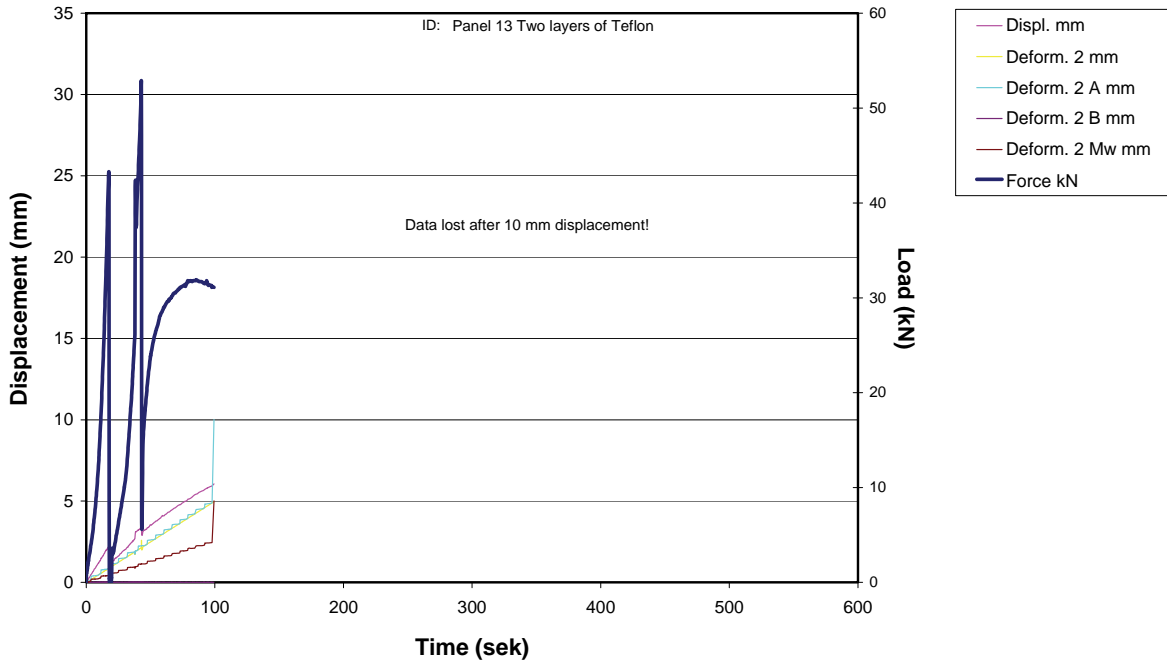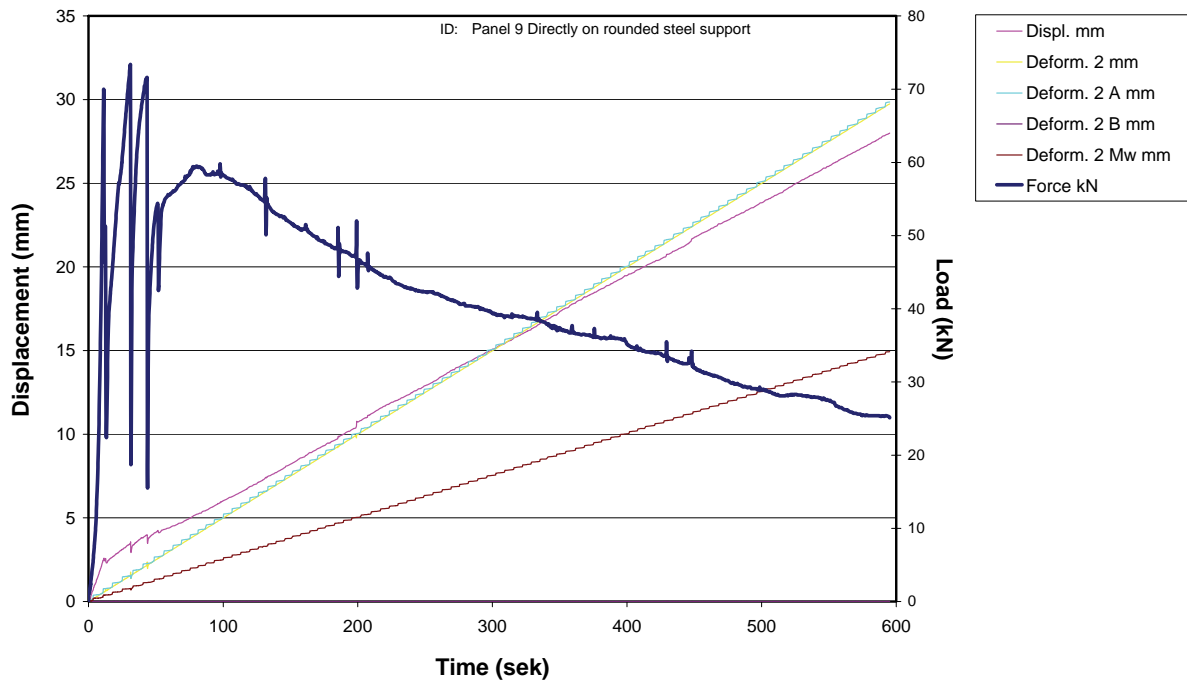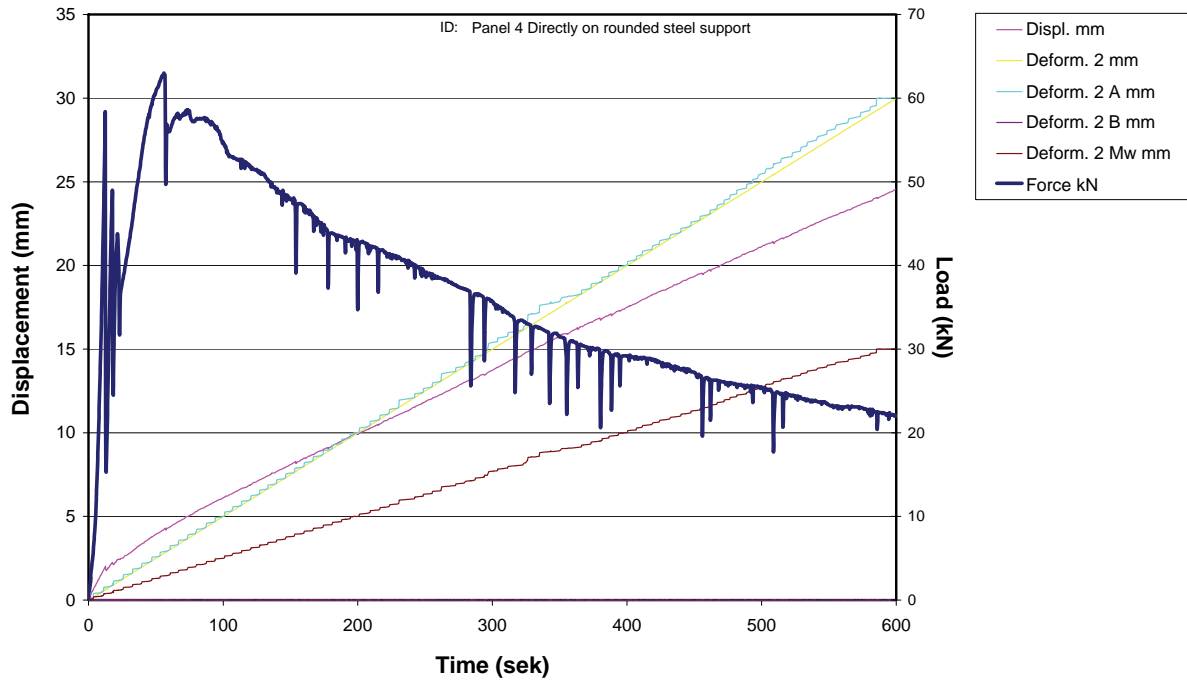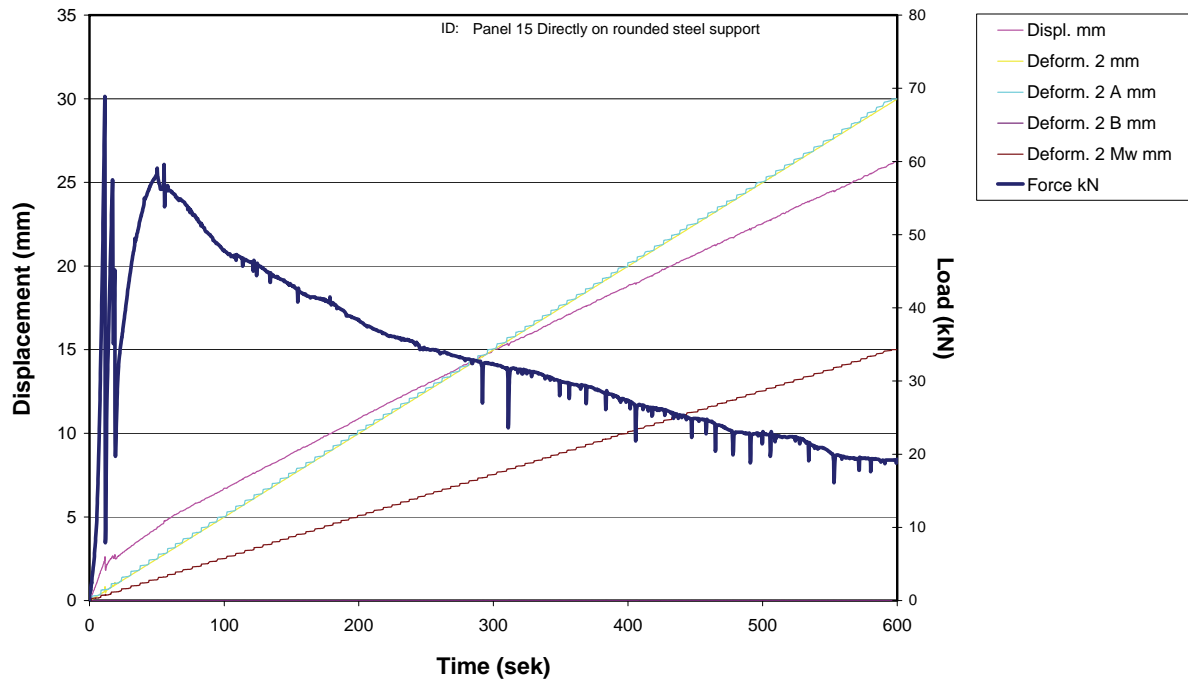| Displacement [mm]	Panel 3 2xPVC+grease	Panel 10 2xPVC+grease	Panel 16 2xPVC+grease	Panel 7 2xPVC+grease	Average 2xPVC+grease	Std.dev.	COV
1,0	17,8	*8,2*	13,2	10,0	12	4,2	34,3 %
3,0	77,6	*41,0*	85,7	67,0	68	19,4	28,7 %
5,0	167,1	*94,1*	159,1	139,9	140	32,7	23,3 %
10,0	360,1	*216,2*	303,0	297,6	294	59,2	20,1 %
14,0	483,3	*297,8*	396,4	403,8	395	76,0	19,2 %
17,3	572,6	*359,1*	463,7	482,5	469	87,6	18,7 %
25,0	740,8	*485,0*	586,6	637,9	613	106,5	17,4 %

APPENDIX 6   Measured load-deflection data, test by test

Channels
"Displ."   = Vertical displacement of the load cell
"Deform. 2"   = Same as "Deform. 2 M"
"Deform. 2A"   = Displacement transducer under the panel. Used for load-cell control.
"Deform. 2B"   = Displacement transducer 2. Not used!
"Deform. 2 M"   = Average of "Deform. 2A" and "-2B".
"Force"   = Load-cell force

Rounded steel support + one layer of Teflon

ID: Panel 11 Teflon

Legend:
- Displ. mm
- Deform. 2 mm
- Deform. 2 A mm
- Deform. 2 B mm
- Deform. 2 Mw mm
- Force kN

ID: Panel 17 Teflon

Legend:
- Displ. mm
- Deform. 2 mm
- Deform. 2 A mm
- Deform. 2 B mm
- Deform. 2 Mw mm
- Force kN

Rounded steel support + two layers of Teflon

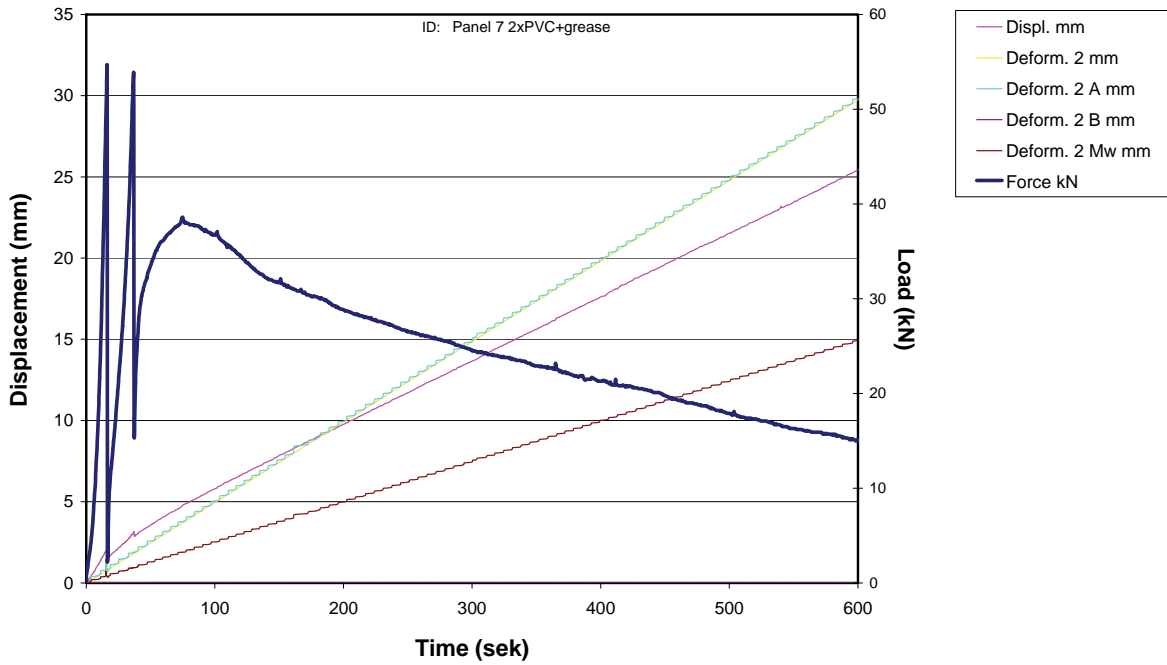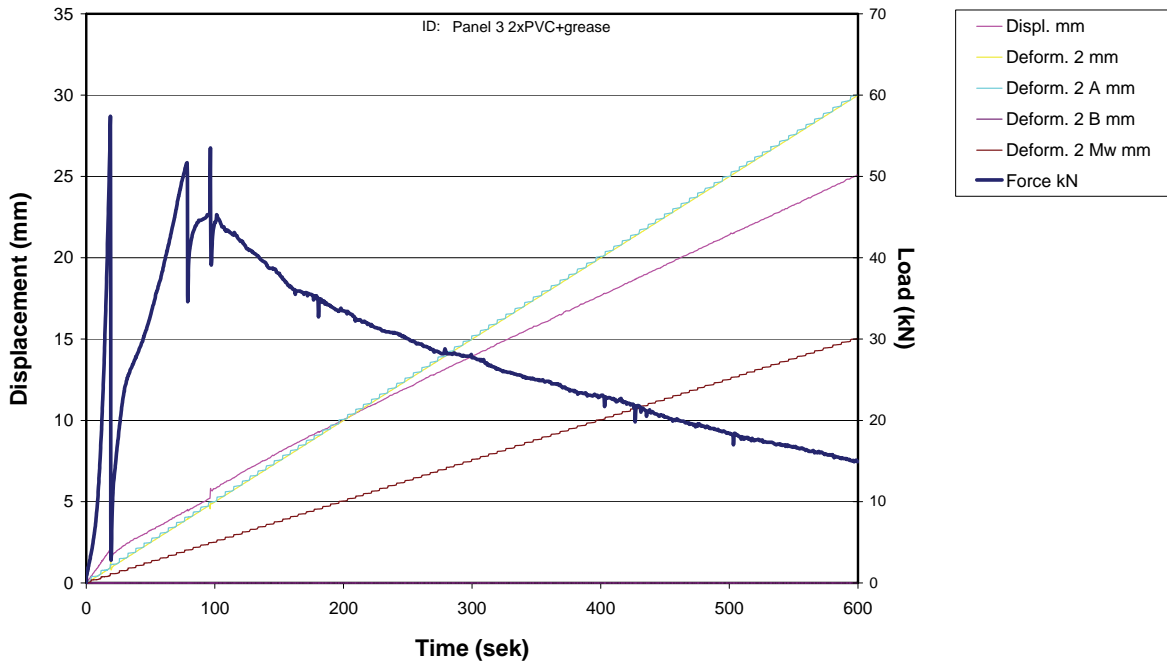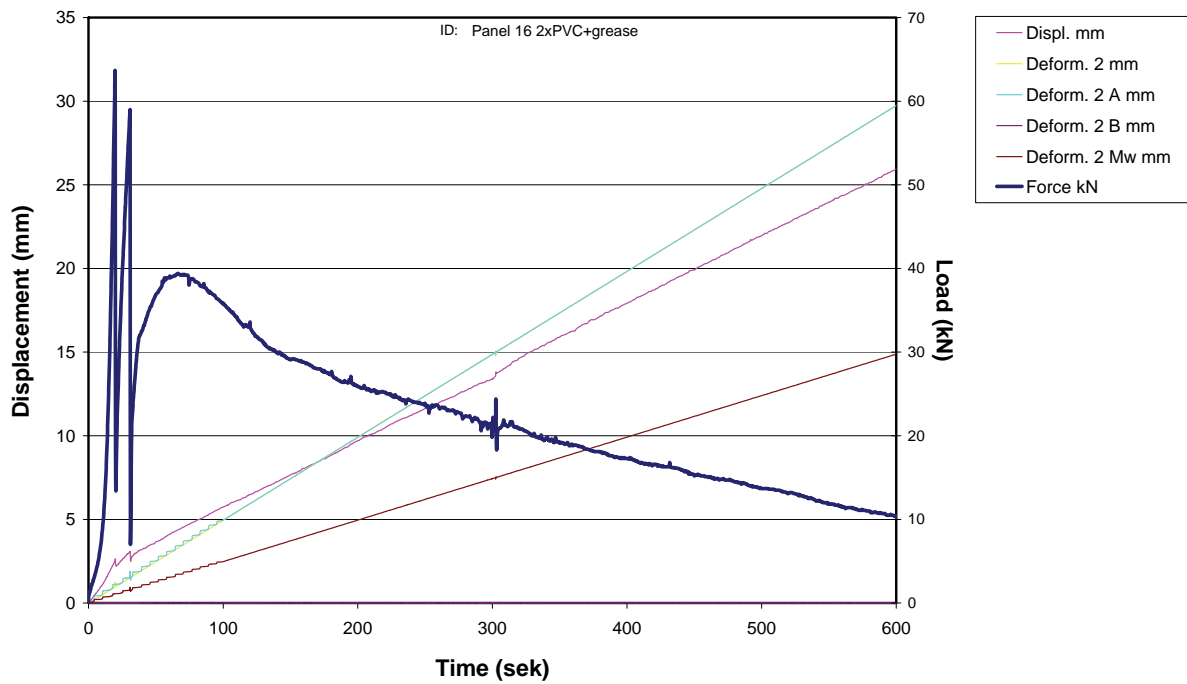- - Panel 6: Data lost completely
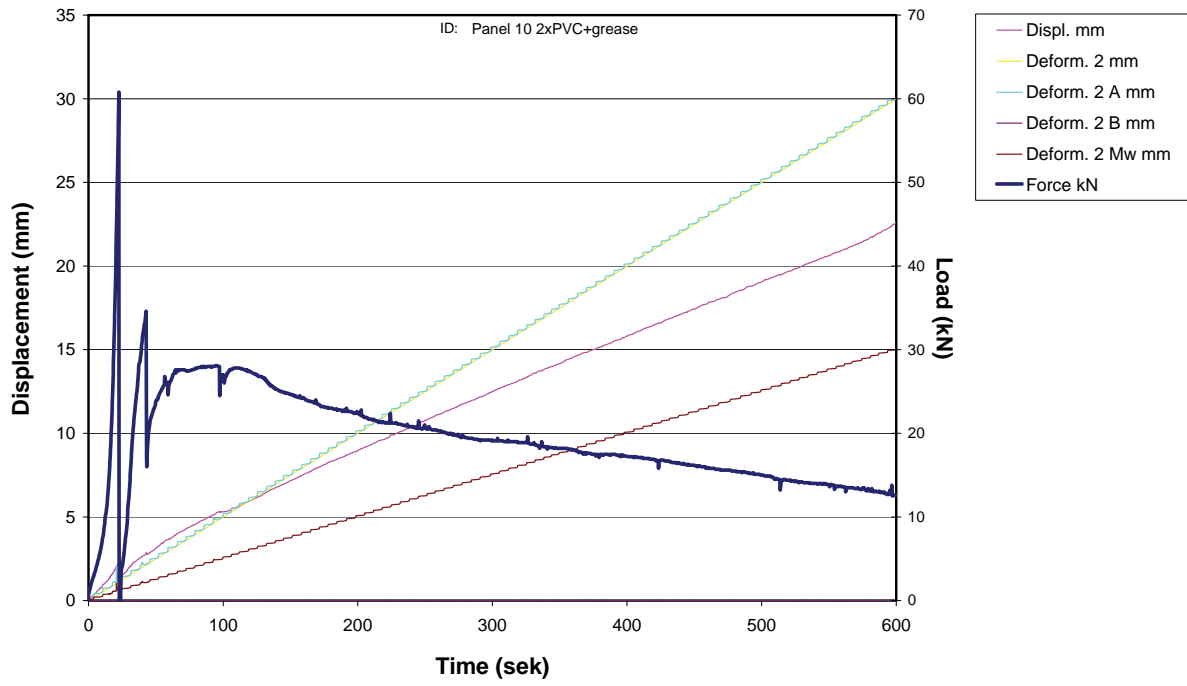- - Panel 13: Data lost after 10 mm displacement
- - Panel 18: Ok

Directly on rounded steel support

ID: Panel 4 Directly on rounded steel support

Legend: Displ. mm, Deform. 2 mm, Deform. 2 A mm, Deform. 2 B mm, Deform. 2 Mw mm, Force kN

ID: Panel 9 Directly on rounded steel support

Legend: Displ. mm, Deform. 2 mm, Deform. 2 A mm, Deform. 2 B mm, Deform. 2 Mw mm, Force kN

ID: Panel 15 Directly on rounded steel support

Legend:
- Displ. mm
- Deform. 2 mm
- Deform. 2 A mm
- Deform. 2 B mm
- Deform. 2 Mw mm
- Force kN

Rounded steel support + two layers of PVC and grease

ID: Panel 10 2xPVC+grease

ID: Panel 16 2xPVC+grease

Directly on wooden support

ID: Panel 5 Directly on wooden support

ID: Panel 8 Directly on wooden support

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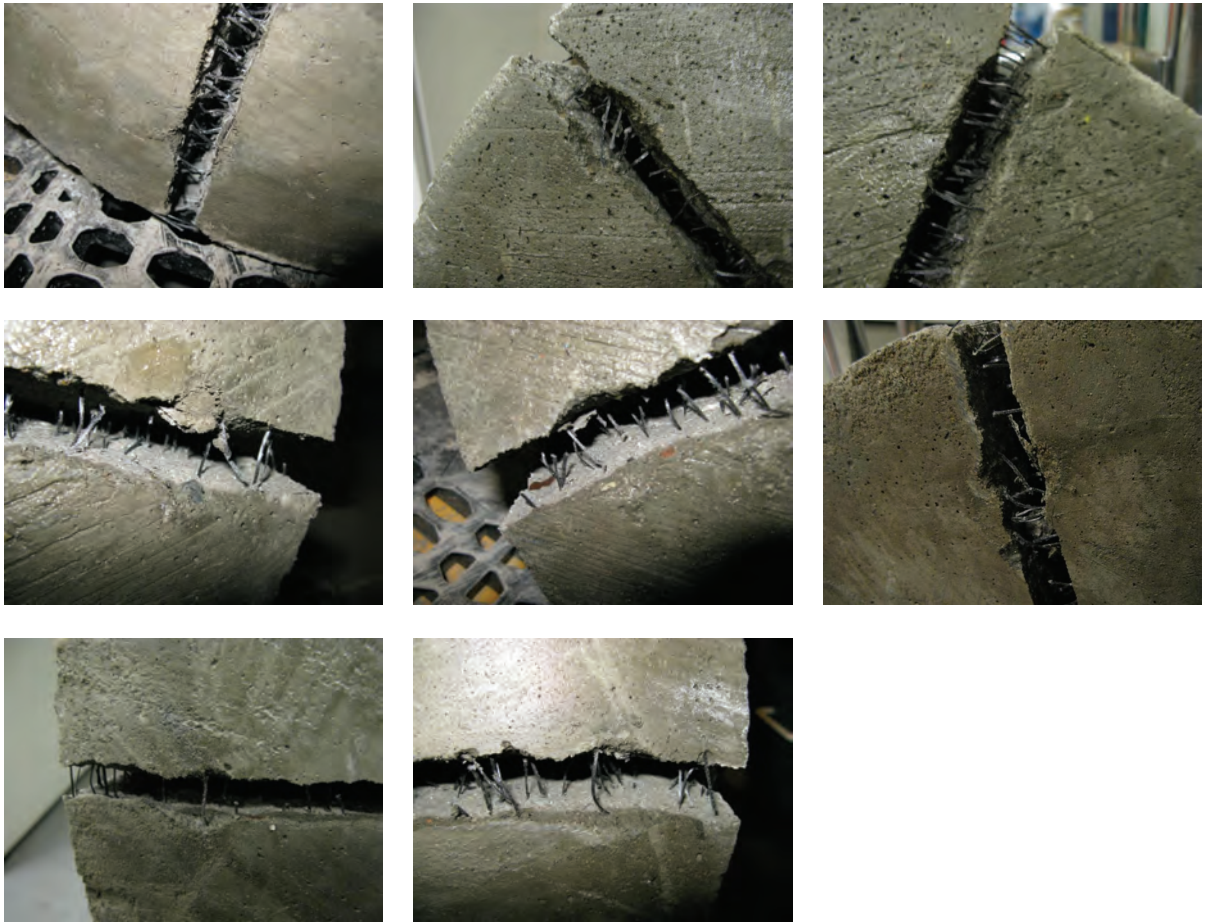
ID: Panel 14 Directly on wooden support
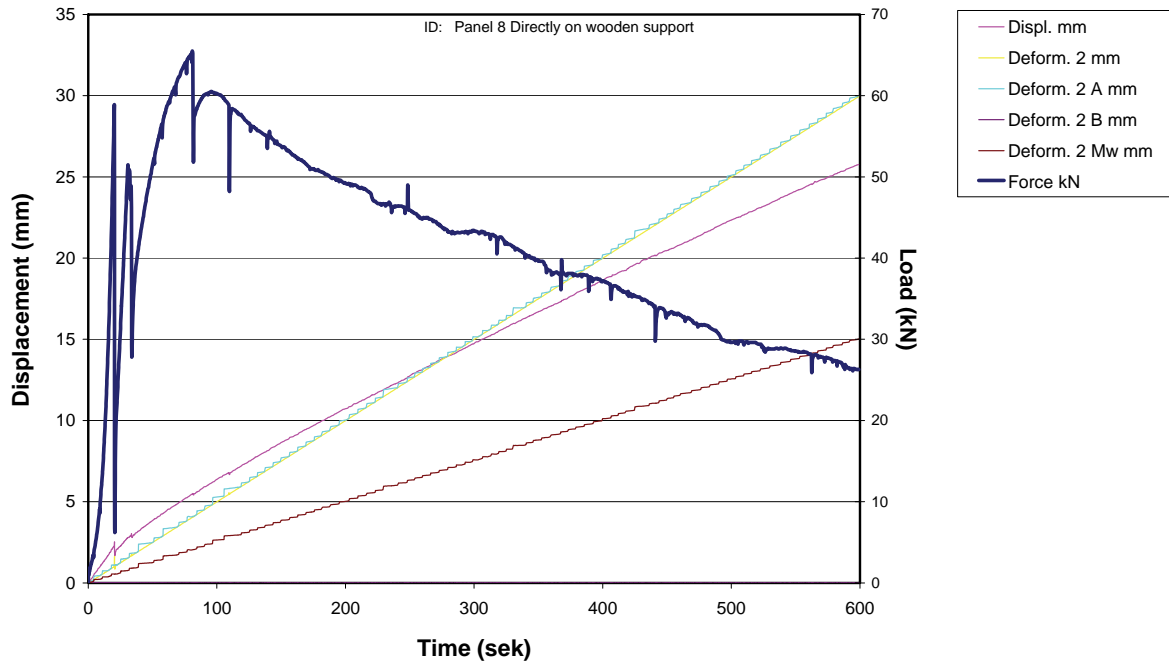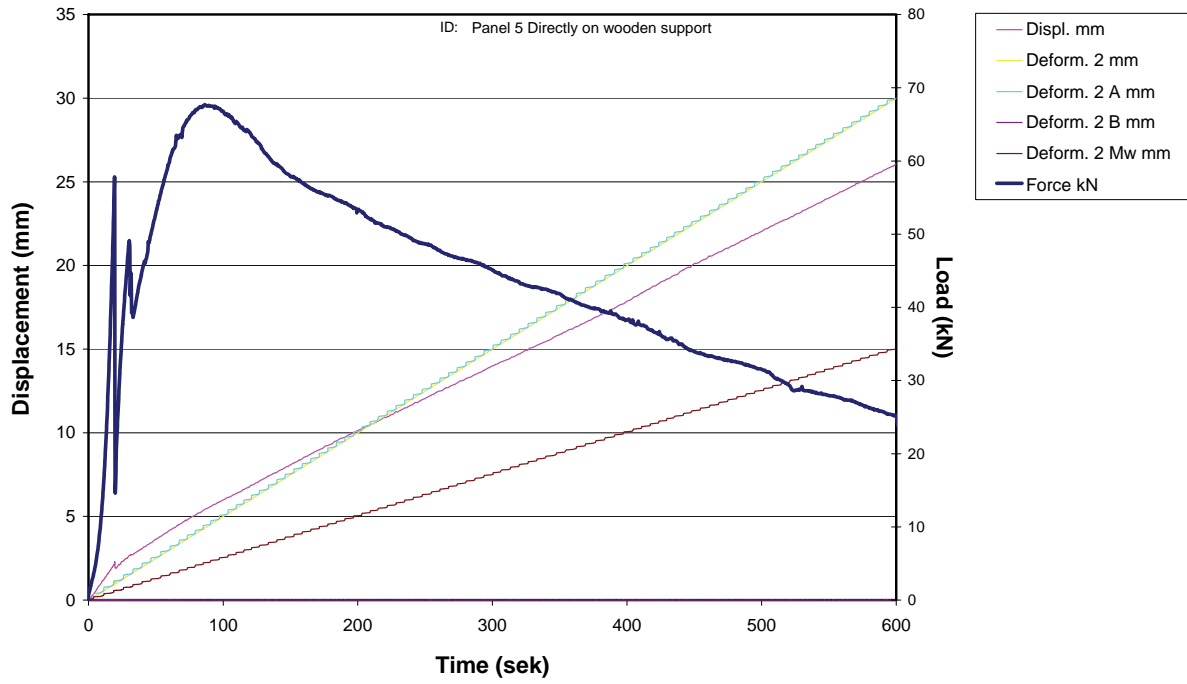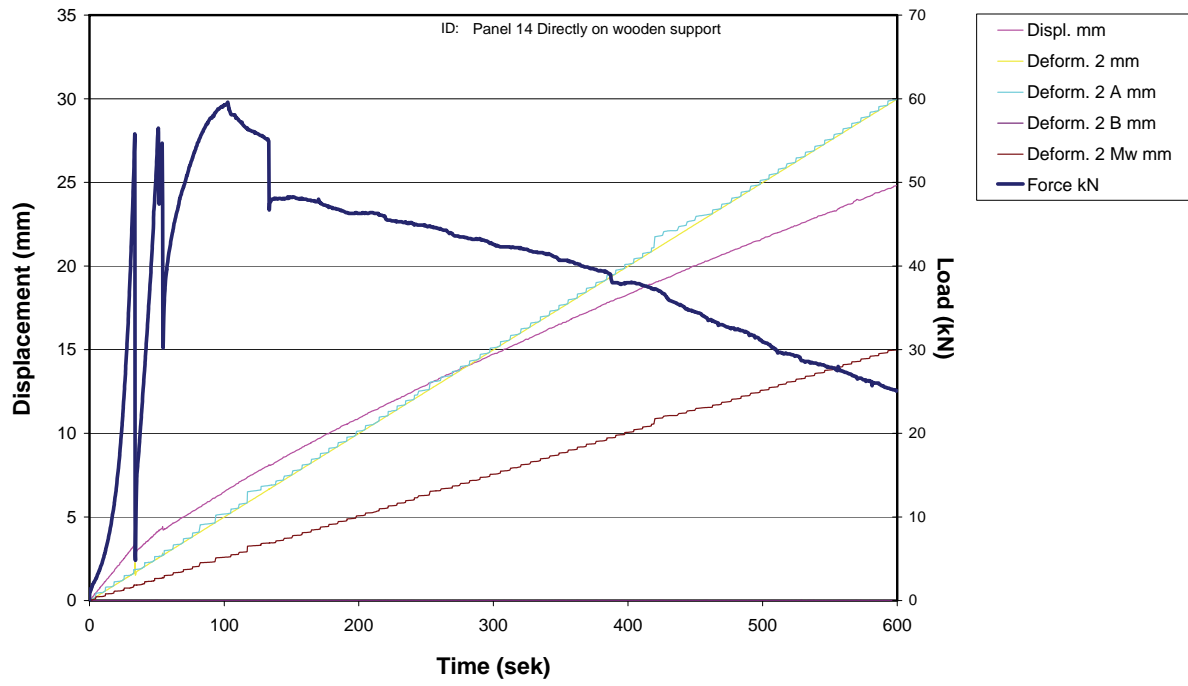
APPENDIX 7   Pictures of crack-zones

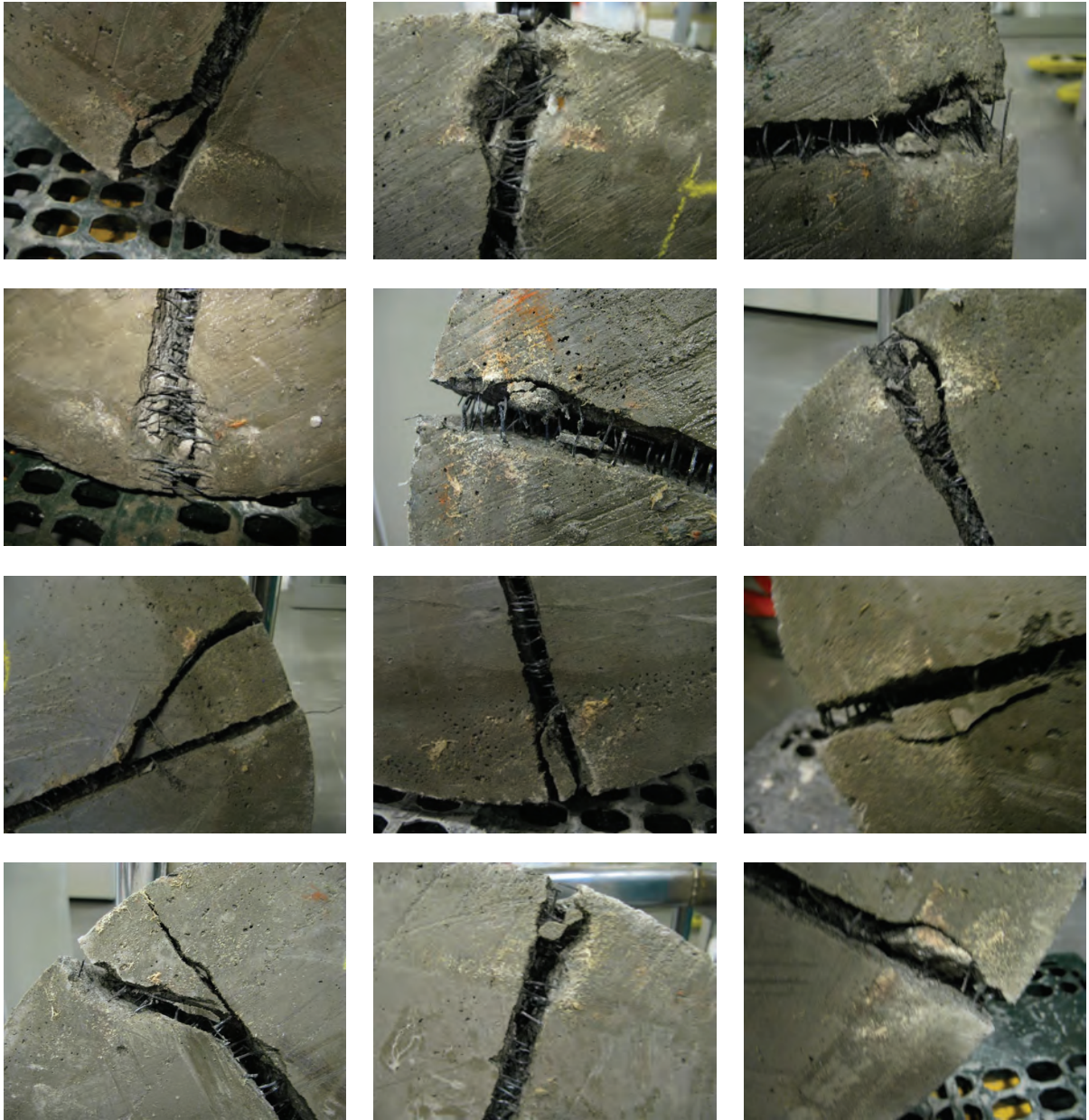**Close-up of crack-zones, Set 3: Steel support, no bedding**
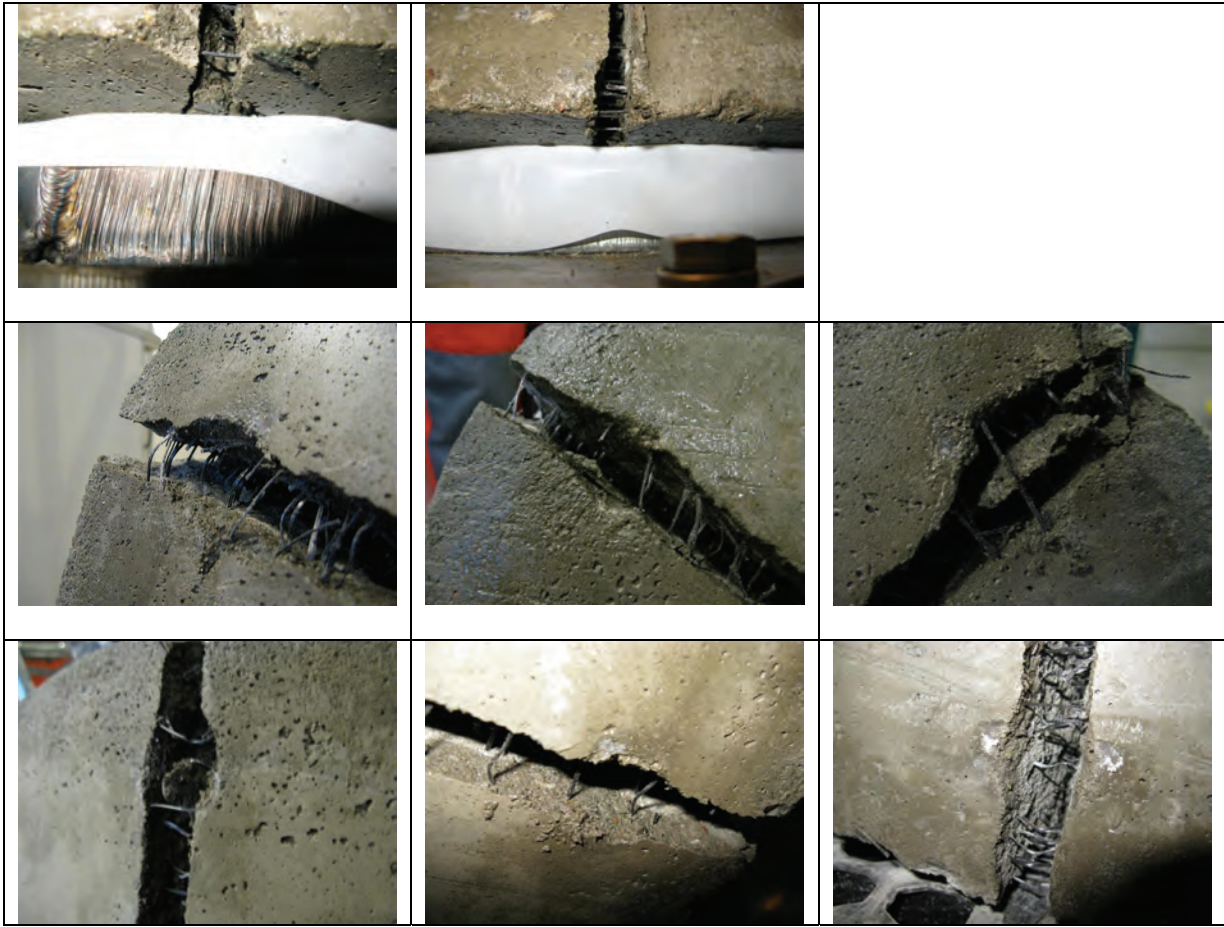
Close-up of crack-zones, Set 1: Steel support, Teflon as bedding material

Close-up of crack-zones, Set 5: Steel support, two layers of Teflon as bedding material

Close-up of crack-zones, Set 2: Steel support, two layers of PVC-membrane + grease as bedding material.

Close-up of crack-zones, Set 4: Wooden support, no bedding

Statens vegvesen

Norwegian Public Roads Administration

Statens vegvesen

Norwegian Public Roads Administration