5. EVALUATION OF THE SHEAR CELL

5.1. Introduction

Specific cases will be analysed in this chapter, which can be generalised as a global behaviour of the shear cells, pointing the factors that influence its design and properties. The main objective is to identify which are the factors that should be modified in order to influence in both strength and flexibility of the shear cell. And which is the range of effective values for design.

The calculations realised to calculate the shear cell properties has been done as explained in the annex I part I.A. The whole set of calculations can be found in annex II; the calculations were done with an Excel spreadsheet that simply automatises the procedure. The values and dimensions used have been chosen according usual measures in real buildings.

5.2. Definition of the parameters

5.2.1. Building dimensions, sheet and purlin distribution

It has been tried to find, some buildings that can be used in between the normal application range. The following elements have been chosen:

Building type	Portal width (mm)	Portal stand (mm)	Shear cell width (mm)
C11	30000	6000	15000
C12	30000	7000	15000
C21	40000	7000	20000
C22	40000	8000	20000
C31	48000	8000	24000
C32	48000	9000	24000

Table 4.1: Selected building dimensions

It is assumed that there is a diaphragm in each side of the building (there is no continuation of the roof sheets through the apex of the roof), so the width of each shear cell is the half of the width of the building.

Once defined the buildings, it will covered with the minimum number of metal sheets (the maximum length of the metal sheets is restrained to 12 meters). The covering schema (always of two sheets) is showed in the table below for one of the sides of the building (with sheet number one and number two). The number of purlins required for each half side of the buildings is showed after; its number depends on the spacing of the purlins (when the value was not exact, it was rounded up to the next natural number)

Building type	Length sheet nº1	Length sheet nº2	Purlin spacing 1500 mm	Purlin spacing 2000 mm	Purlin spacing 2500 mm
C11	8000	7000	10	8	6
C12	8000	7000	10	8	6
C21	10000	10000	14	10	8
C22	10000	10000	14	10	8
C31	12000	12000	16	12	10
C32	12000	12000	16	12	10

Table 4.2: Distribution of sheet lengths and purlins for each building type

It can be seen that the structural schema is of 4 or more purlins per sheet

	Purlin spacing 1500 mm	Purlin spacing 2000 mm	Purlin spacing 2500 mm
C1	5,3	4	3,2
C2	6,7	5	4
C3	8	6	4,8

Table 4.3: Number of purlins per sheet length (the longest sheet)

5.2.2. Metal sheets

Eight metal sheets have been chosen. Four are from the producer Thyssen-krupp (www.tks-bau.com), which only produces in Germany, and the other four are from the producer Europerfil (www.europerfil.es). Those sheets were chosen because they have similar behaviour in bending (similar heights) but different behaviour in shear. The dimensions of the metal sheets can be found in the next Tables:

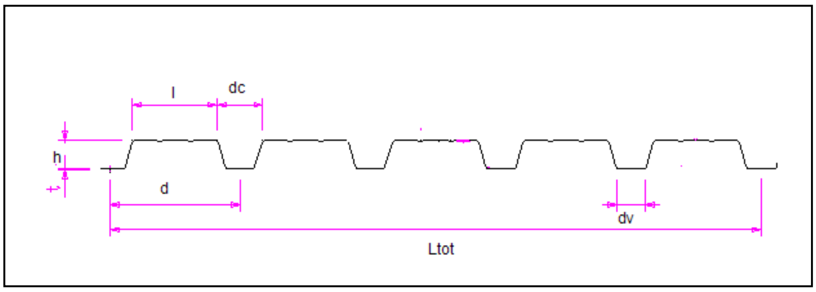

Fig 4.1: measures in the metal sheet

5.2.2.1. Thyssen-krupp

Name	L_{tot}(mm)	d(mm)	d_v(mm)	l(mm)	h(mm)	Crest stiffeners?	Webs stiffeners?	Number valleys	Thickness
								n_{fv}	t(mm)
35,1	1035	207	40	119	32	no	no	6	0,88
40,1S	915	183	40	119	40	yes	no	6	0,88
50,1	1000	250	54	135	48,5	no	no	5	0,88
85,1	1120	280	40	119	83	yes	yes	5	0,88

Table 4.4: Dimensions of the metal sheets

The values of the K_1 and K_2 are calculated with the interpolation of the table 6 and table 7 in annex 3.
If the values did not exist, a linear propagation was done.

Name	h/d	l/d	θ	K_1	K_2	D_x	D_y
	-	-	degrees	-	-	KNmm	KNmm
35,1	0,15	0,57	36,87	0,098	0,787	11	19245
40,1S	0,22	0,65	16,70	0,207	1,27	10	35663
50,1	0,19	0,54	32,16	0,082	0,692	11	45925
85,1	0,30	0,43	36,09	0,176	1,728	10	119001

Table 4.5: Mechanical properties in shear of the metal sheets

5.2.2.2. <u>Europerfil</u>

Name	L_{tot}(mm)	d(mm)	d_v(mm)	l(mm)	h(mm)	Crest stiffeners?	Webs stiffeners?	Number valleys	Thickness
								n_{fv}	t(mm)
eurobase 40	1065	266	20	190	40	yes	yes	5	0.8
eurobase 48	1000	250	20	180	48	yes	no	5	0.8
eurobase 56	950	238	20	168	56	yes	yes	5	0.8
eurobase 67	810	202,5	30	132,5	67	yes	yes	5	0.8

Table 4.7: Dimensions of the metal sheets

Name	h/d	l/d	θ	K_1	K_2	D_x	D_y
	-	-	degrees	-	-	KNmm	KNmm
eurobase 40	0,15	0,71	34,99	0,277	1,271	11	17535
eurobase 48	0,19	0,72	27,51	0,281	1,233	11	27819
eurobase 56	0,24	0,71	24,06	0,4	1,79	10	40854
eurobase 67	0,33	0,65	16,62	0,414	2,552	9	77692

Table 4.8. Mechanical properties for shear of the metal sheets

5.2.3. Fastening patterns

The third key parameter is the fastening pattern in the roof. In the ECCS recommendation there are four possibilities (see fig. 4.2):

1. Fastened each trough
2. Fastened in alternate troughs
3. Fastened in alternate troughs everywhere except on the connection of the sheet and in the ends
4. Fastened in alternate troughs except in the ends of the building

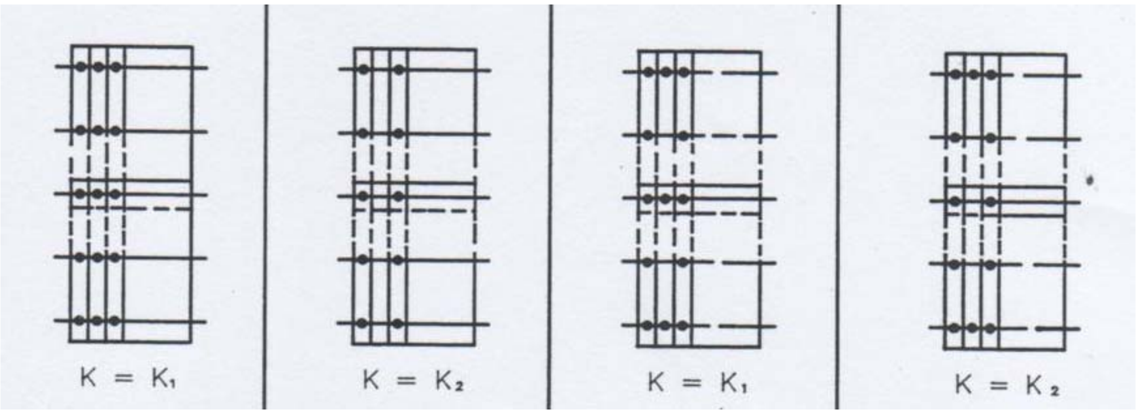

Fig 4.2: Fastening patterns in ECCS

The other factor is if this is a direct connection (shear connection elements or fastened directly to the rafter) or indirect connection, transmission of the shear through the purlins. See examples in fig 4.2

In order not to complicate too much the amount of information, the two extreme cases, fastening in all the troughs and in alternate troughs are considered, the other two lay in between.

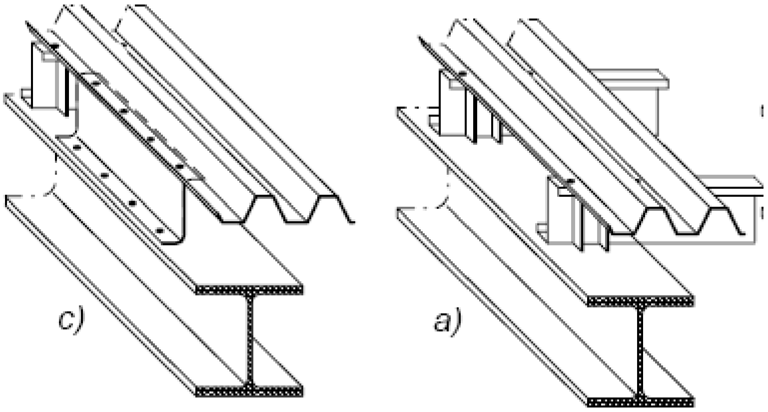

Fig 4.3: left: direct connection with shear transmitters, right: indirect connection through purlins

5.3. Shear cell's flexibility and ultimate stress evaluation

The values chosen for each analysis are different and come from the list in annex II. A comparison of absolute values between the graphics can not be made; it should be made within them

In each graphic 4 lines can be seen:

- cDE: *Direct* fastening pattern and with *Every* trough fastened
- cDA: *Direct* fastening pattern and with *Alternate* trough fastened
- cIE: *Indirect* fastening pattern and with *Every* trough fastened
- cIA: *Indirect* fastening pattern and with *Alternate* trough fastened

5.3.1. Evaluation of the influence of different parameters

5.3.1.1. Shear cell dimensions

The same kind of metal sheet, purlin spacing, fasteners type and distribution are chosen, and the dimensions of the shear cell are modified. How does this influence to the flexibility and the ultimate shear force?

The building type refers to the building type explained in table 4.1; the buildings 2CXX consider that the whole roof is a diaphragm

5.3.1.1.1. Flexibility

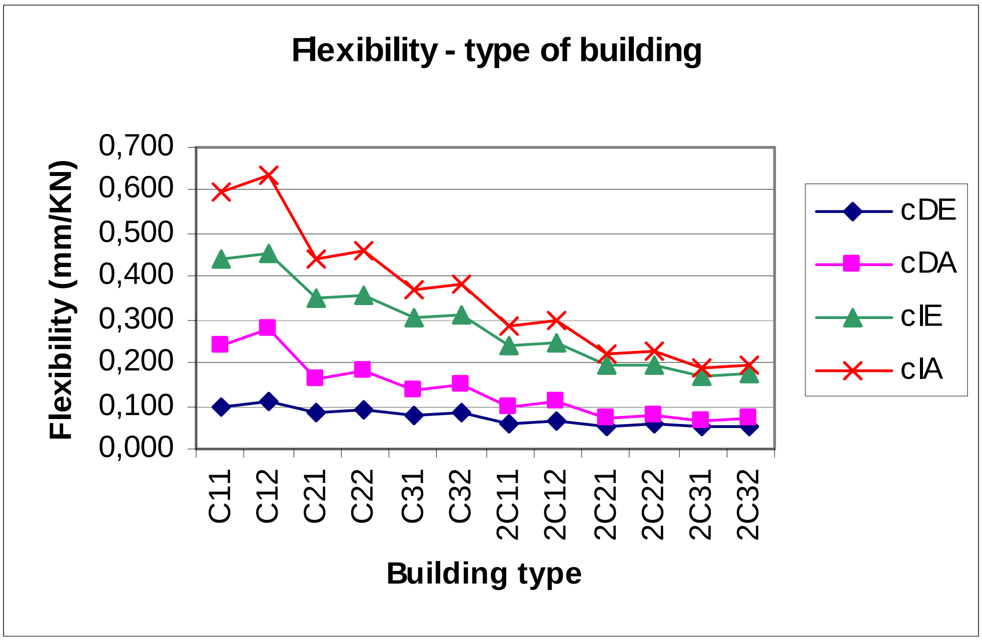

Fig 4.4: Evolution of the flexibility depending on the type of building

In the graphic can be noticed that:

- The wider the diaphragm (bigger *b*), the smaller is the flexibility. The flexibilities' decrease gets smaller, as the absolute value of the diaphragm's width gets bigger.

- The shorter the diaphragm (less *a*), the less flexible it is. As the spacing of the portals gets bigger, the flexibility of the shear cell grows.
- The absolute value of the two previous parameters loses importance as the fastener pattern gets stiffer (the shear cell grows in dimension)

The dimensions of the building are probably something where the designer can not influence so much when gets to this point of designing. Maybe the most effective way is to try to connect the two sides of the building, allowing the diaphragm to act as one and not two separate ones.

5.3.1.1.2. Ultimate shear force S in the panel

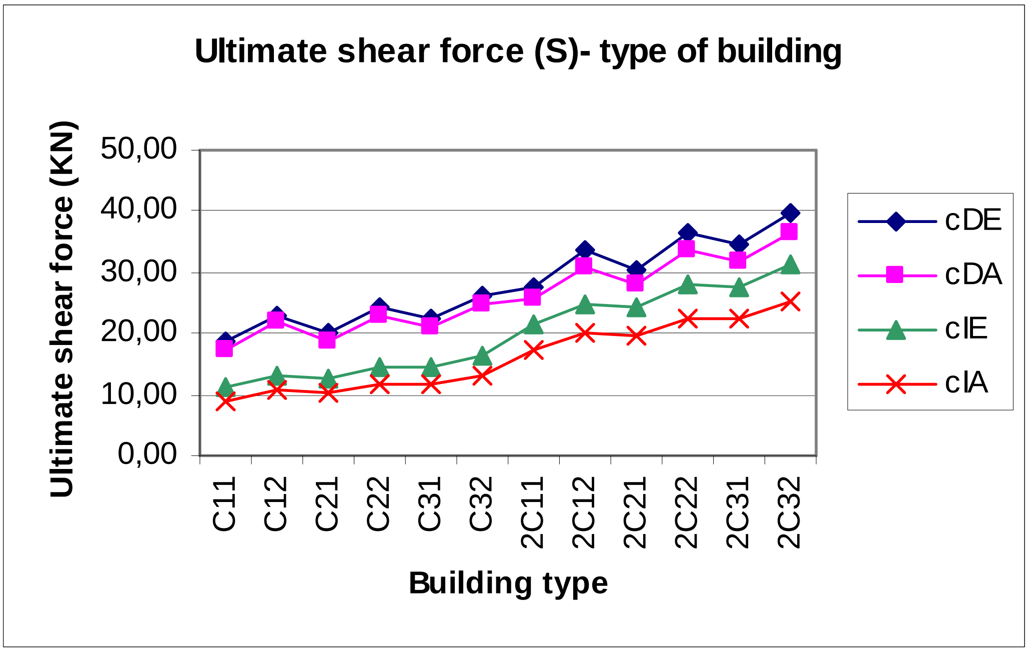

Fig 4.5 Evolution of the ultimate shear stress depending on the type of building

In the graphic can be noticed that:

- Direct fastening:
  - The ultimate shear force grows as the building's width gets bigger (↑b)
  - The ultimate shear force is bigger if the portal spacing is bigger (↑a)
- Indirect fastening:
  - The purlin/rafter or connection with end rafter, which is independent on the spacing of the portals, is usually the limiter strength and not the seam anymore. That's why just the fact that the building gets wider (↑b) modifies the ultimate strength, and not if (↑a)

5.3.1.2. Spacing of purlins

The same kind of metal sheet, building, purlins, fasteners type and distribution are chosen, and the spacing of the purlins is modified. How does this influence to the flexibility and the ultimate shear force?

5.3.1.2.1. Flexibility

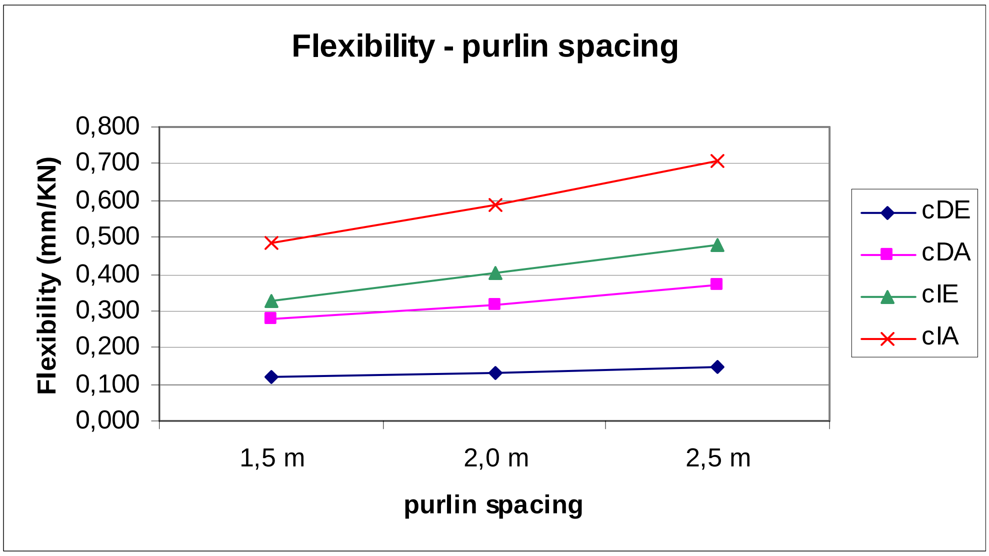

Fig 4.6: Evolution of the flexibility depending on the purlins' spacing

In the graphic can be noticed that:

- The wider the spacing the bigger is the flexibility. The difference depends on the used metal sheet. It can not be noticed in the graphic, but the slope of the line can vary depending on the metal sheet used.

5.3.1.2.2. Ultimate shear force S in the panel

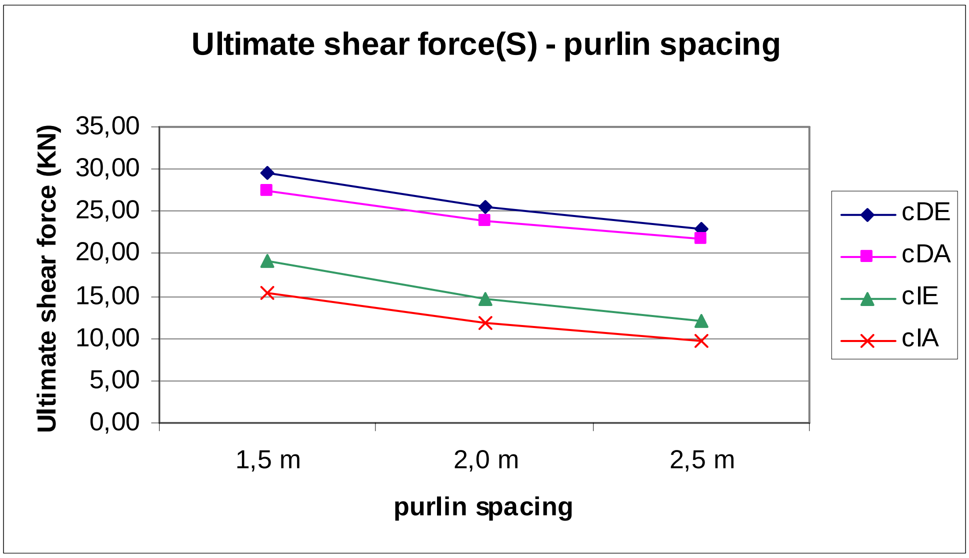

Fig 4.7 Evolution of the ultimate shear force depending on the purlins' spacing

In the graphic can be noticed that:

- The wider the spacing, the lesser the strength, mainly because the number of purlins is less, so less number of fastening points.

The purlins have what can be called a negative relation compared to the building type. Here the more we space the purlins, the shear cell is more flexible and less resistant. In the building, the bigger the shear cell was, the stronger and more resistant it was.

5.3.1.3. <u>Type of fasteners</u>

The same kind of metal sheet, building, purlins, purlin spacing and fastener distribution are chosen, and the spacing of the type of sheet/purlin fastener is modified. How does this influence to the flexibility and the ultimate shear force?

5.3.1.3.1. Flexibility

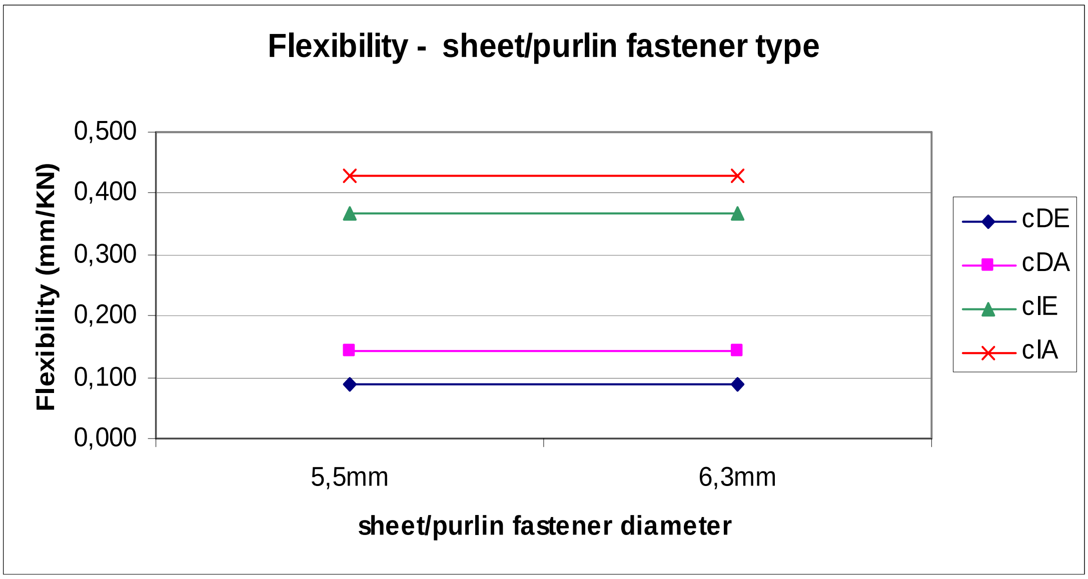

Fig 4.8: Evolution of the flexibility depending on the sheet/purlin fastener's type

In the graphic can be noticed that:

- The type of fasteners does not affect the flexibility of the shear cell. Neither the use of sheet/purlin fasteners nor the seam fasteners nor sheet/shear transmitters (the graphics are the same) modify the flexibility of the shear cell.
- The value chosen as flexibility of the elements does it of course.

5.3.1.3.2. Ultimate shear force S in the panel

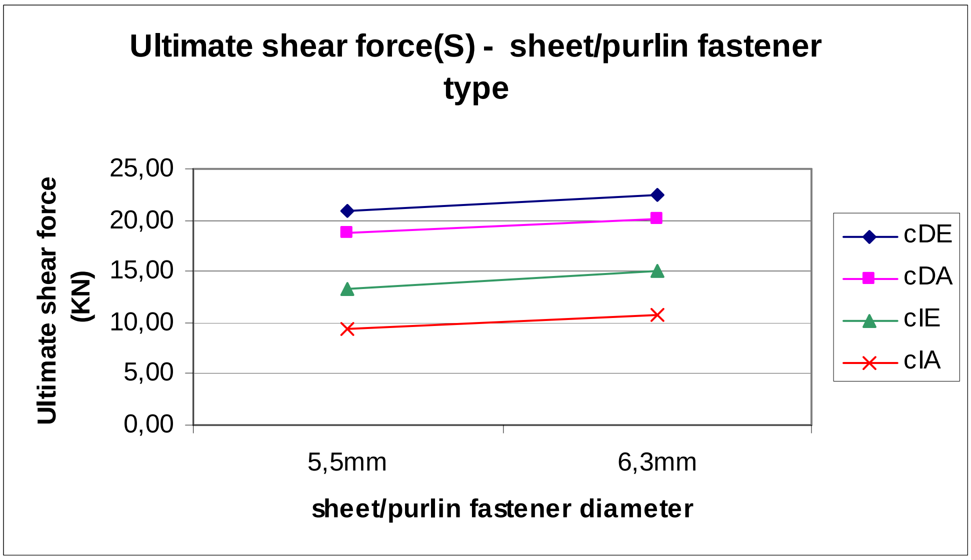

Fig 4.9 Evolution of the ultimate shear force depending on the sheet/purlin fastener's type

In the graphic can be noticed that:

- The type of fasteners does affect the shear strength. The bigger the diameter (higher strength) the higher the ultimate shear.

5.3.1.4. <u>Seam fasteners</u>

The same kind of metal sheet, building, purlins, purlin spacing are chosen, and the spacing, and seam fastener's type is modified. How does this influence to the flexibility and the ultimate shear force?

5.3.1.4.1. Flexibility

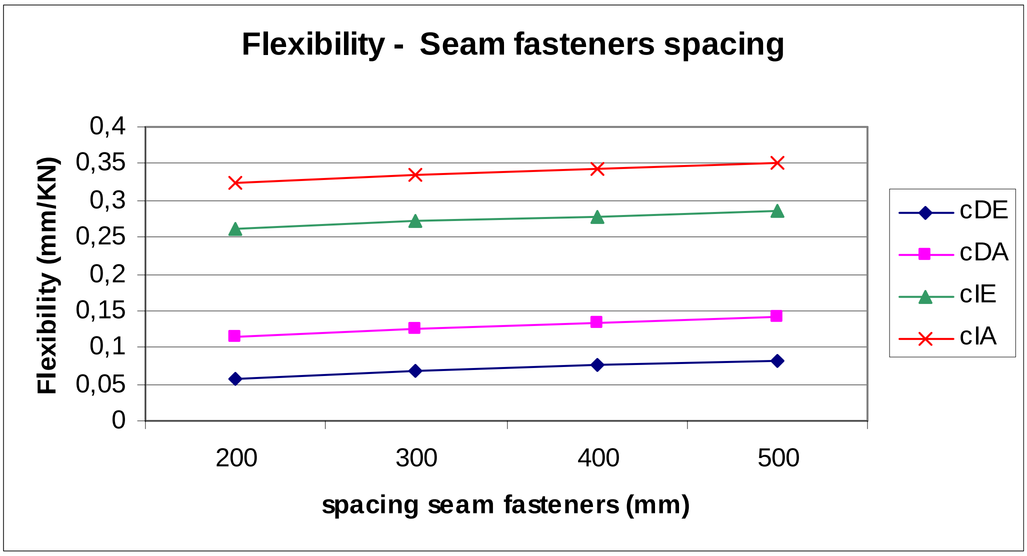

Fig 4.10 Evolution of the flexibility depending on the seam fastener's spacing

In the graphic can be noticed that:

- The bigger the spacing the bigger the flexibility. The difference though it is not no significantly bigger.

5.3.1.4.2. Ultimate shear force S in the panel

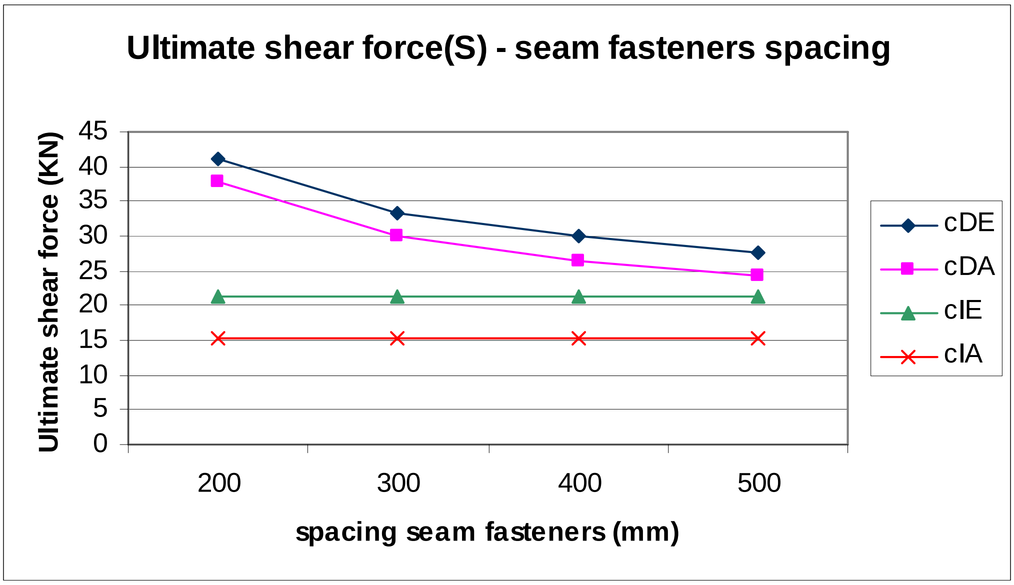

Fig 4.11 Evolution of the ultimate shear force depending on the seam fastener's spacing

In the graphic can be noticed that:

- Direct fastening: The bigger the spacing the smaller the ultimate stress. It can be noticed in this case, the seam is the limiter factor
- Indirect fastening: As mentioned, in indirect the responsible of the ultimate shear force is the purlin connection or the end sheet connection. That's why the spacing has no influence.

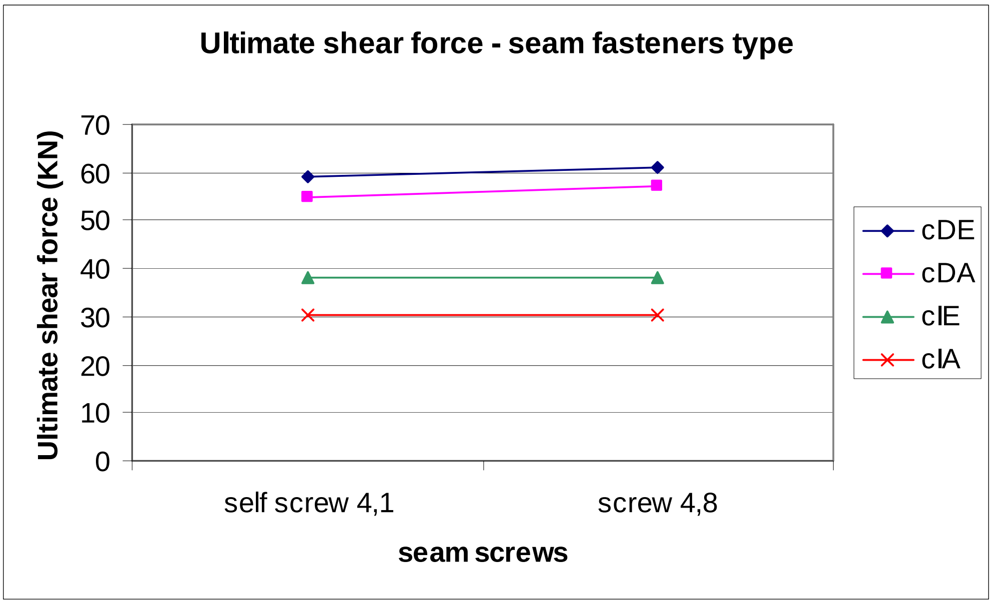

Fig 4.12 Evolution of the ultimate shear force depending on the seam fastener's type

In the graphic can be noticed that:

- Direct fastening: The bigger the diameter of the screw the bigger the ultimate stress. It can be noticed in this case, the seam is the limiter factor
- Indirect fastening: The responsible of the ultimate shear force is the purlin connection on the end sheet. That's why the fastenings type has no influence.

5.3.1.5. Sheet/Shear transmitter's fasteners

The same kind of metal sheet, building, purlins, purlin spacing, fasteners are chosen, and the sheet/shear transmitter fasteners spacing is modified. How does this influence to the flexibility and the ultimate shear force?

5.3.1.5.1. Flexibility

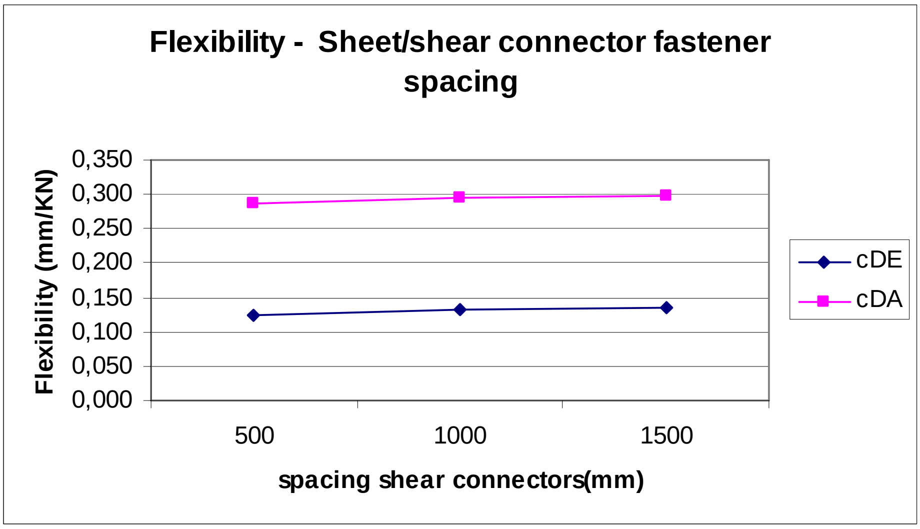

Fig 4.13 Evolution of the flexibility depending on the sheet- shear transmitter fasteners spacing

In the graphic can be noticed that:

- The bigger the spacing the bigger the flexibility. The difference though it inestimable

5.3.1.5.2. Ultimate shear force S in the panel

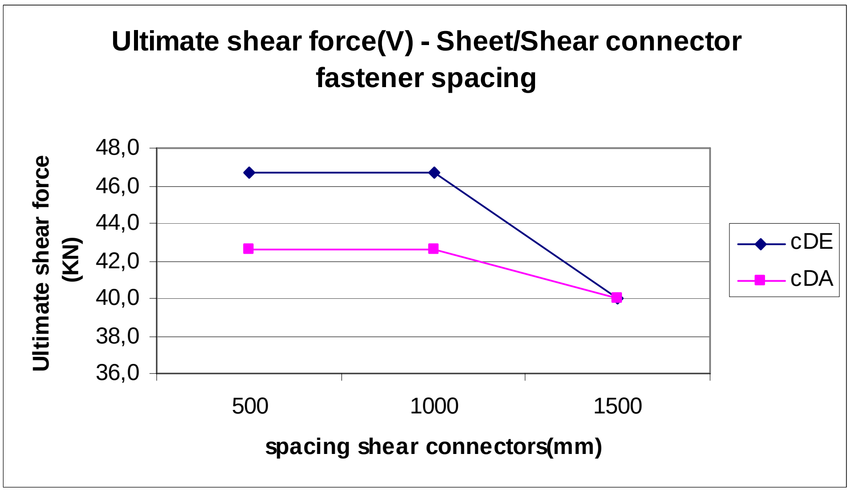

Fig 4.14 Evolution of the ultimate shear force depending on the sheet- shear transmitter fasteners spacing

In the graphic can be noticed that:

- If the distribution of fasteners is enough the Ultimate shear force, remains constant as the end sheet failure is not the limiter factor. If the number of fasteners is reduced as the ultimate shear force depends on them, it is reduced.
- It should be tried that this failure mode is never the limiter factor, as the number of fasteners can bring again the failure mode to the seam.

5.3.1.6. <u>Metal sheets</u>

The same kind of building, purlins and fastenings are chosen and the metal sheet is modified. How does this influence to the flexibility and the ultimate shear force?

5.3.1.6.1. Flexibility

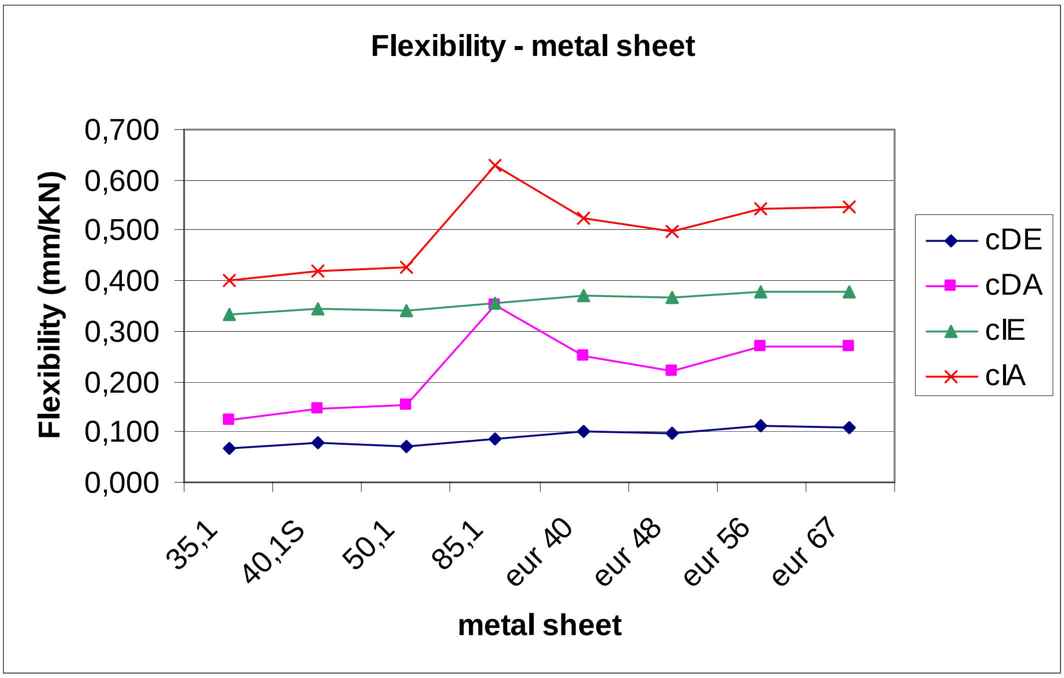

Fig 4.15 Evolution the flexibility depending on the metal sheet chosen

In the graphic can be noticed that:

- If the metal sheet is fastened every though the difference between metal sheets is not highly significant, mainly because $c_{1.1}$ is a relatively small value compared to the rest.
- If the metal sheet is fastened in alternative troughs, the metal sheet chosen do influence a lot. Mainly because $c_{1.1}$ is then a significant value in the flexibility. Mainly driven by the parameters d and K_2

5.3.1.6.2. Ultimate shear force S in the panel

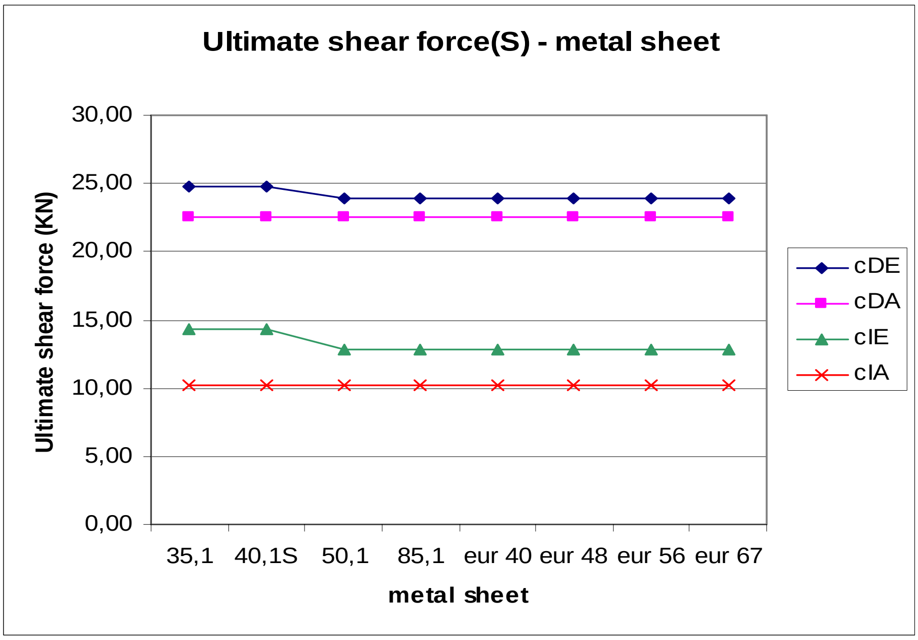

Fig 4.16 Evolution of the ultimate shear force depending on the metal sheet chosen

In the graphic can be noticed that:

- The metal sheet has no influence and is the same for all the metal sheets (that is because the non-allowable modes have no influence for so short spans.
- The reason because two values have a higher ultimate stress is that those two metal sheets have 6 valleys instead of 5, they have one fastener more when fastened each through.

5.3.1.7. Purlins/rafter/sheet connection

Let's compare now the influence of the values depending if there are simple cleats or stiffened ones. As simple ones the values proposed by the ECCS and the calculation of the cleat placed as example in the ECCS calculated with the SBI formulation (see Annex I table 1) has been taken, and as rigid the values proposed in both formulations (can be found in the table 4.10)

		ECCS cleat With SBI	ECCS flex	ECCS Rigid	SBI rigid
Thickness	mm	9.4	-	-	-
depth	mm	198	-	-	-
Width	mm	127	-	-	-
E	N/mm2	210000	--	-	-
fyk	KN/mm2	235	-	-	-
flexibility	mm/KN	1.01	1.4	0.38	0,3
Ultimate strength	KN	4.85	4.4	7.2	8

Table 4.10. Flexible and rigid cleats

5.3.1.7.1. Flexibility

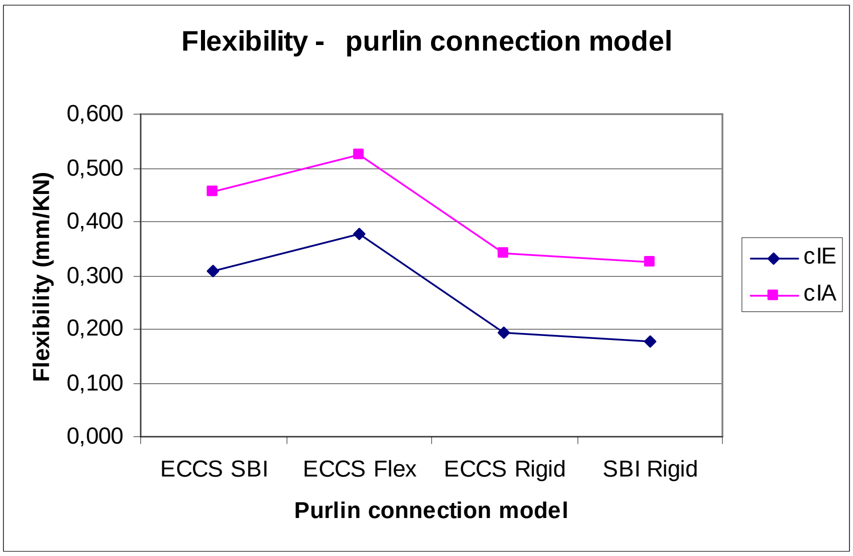

Fig 4.17 Evolution of the flexibility depending on the purlin connection model

In the graphic can be noticed that:

- The use of rigid cleats reduces significantly the values of rigidity respect to the use of not stiffened ones
- The slight difference of the cleats flexibility values of round 0.1 mm/KN is showed as a difference on 0.5 mm/KN of the flexibility of the shear cell. The difference on the rigid it is not so noticeable.

5.3.1.7.2. Ultimate shear force S in the panel

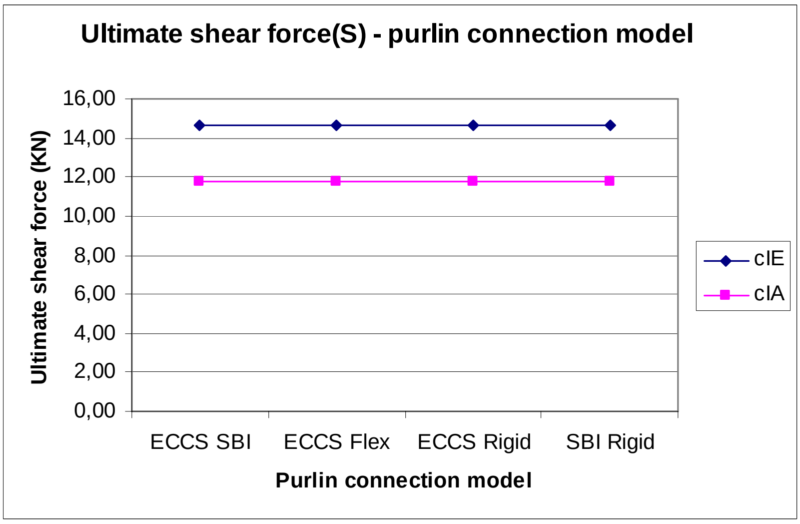

Fig 4.18 Evolution of the ultimate shear force depending on the purlin connection model

- It has no influence on the ultimate shear force, as the ultimate shear force is controlled by the end sheet connection.

5.3.2. Range values for the different fastening patterns

In the following table there are the maximum, minimum, mean value and the mean deviation of the muster (see annex II for the whole list) for the four studied cases.

	cDE	cDA	cIE	cIA	cDE (S)	cDA(S)	cIE(S)	cIA(S)
Maximum	0,194	0,815	0,619	1,248	40,87	36,59	27,26	19,47
Medium	0,101	0,272	0,381	0,559	28,12	26,24	15,85	12,31
Minimum	0,059	0,100	0,231	0,277	19,68	18,71	9,33	7,47
Deviation	0,028	0,139	0,093	0,192	4,46	4,04	3,81	2,89

Table 4.11 Statistical data from shear cell output

The conclusions that can be extracted is that:

- The maximum shear force allowed in a shear cell is round the 40 KN
- The absolute range of flexibilities is from 0.06 to 1.3 mm/KN. But that a more restricted vision would be from 0.1-0.8 mm/KN
- The fastening pattern has a big influence, especially for certain metal sheets.

The values on the previous table can bring to a mistake on the conception, as the maximum shear force do not necessary meets with the one with minimum flexibility. That's why the following graphics are have been plotted, where for each case the flexibility and ultimate force have been plotted for the different kinds of fastening patterns. It is then easier to see which values are possible and not.

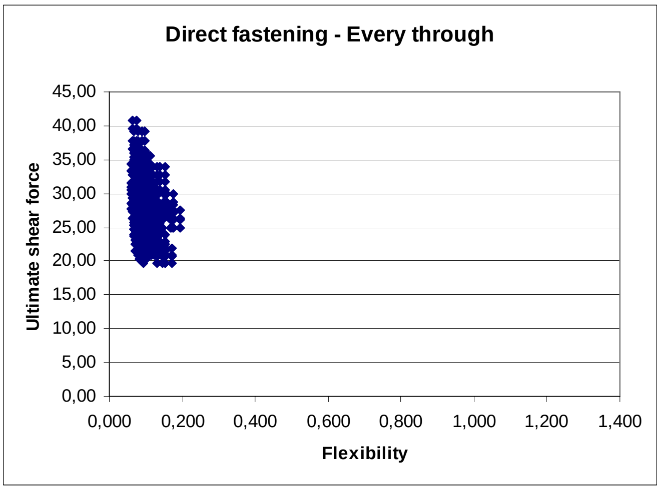

Fig 4.19 elation ultimate shear force- flexibility for a shear cell fastened in every tough and shear connectors

The values are quite well ranged in flexibility and do vary substantially in the ultimate shear force that can be absorbed.

- The range of flexibilities is from 0.06 to 0.19 mm/KN

- The range of strengths (S) is from 20 KN to 40 KN
- Statistically c=0.10±0.03 mm/KN and S=28±4 KN

On the next graphic the same values are plotted and differentiated depending on the building type. It seems difficult to identify a pattern that can allow the identification of values "a priori".

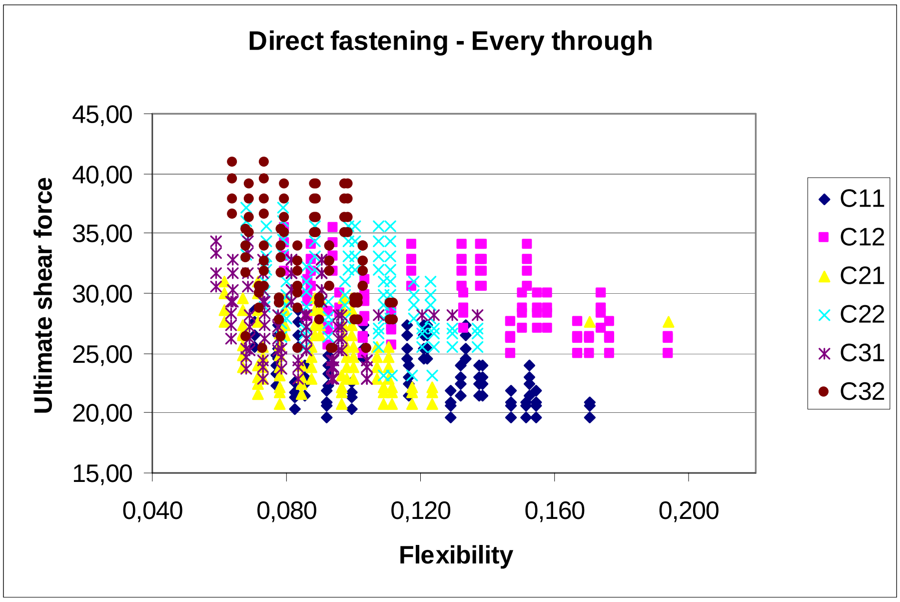

Fig 4.20 relation ultimate shear force- flexibility for a shear cell fastened in every tough and shear connectors. Based on the dimensions of the shear cell

The conclusion that can be extracted is that playing with the factors mentioned in the first part of this chapter, it is possible to find the optimum configuration, no matter the type of building.

Let's examine the other fastening patterns:

The direct but with alternate shows a big difference in flexibilities, mainly because the metal sheet do not behave so homogeneous when fastened in alternate troughs and a more central range strength' s values.

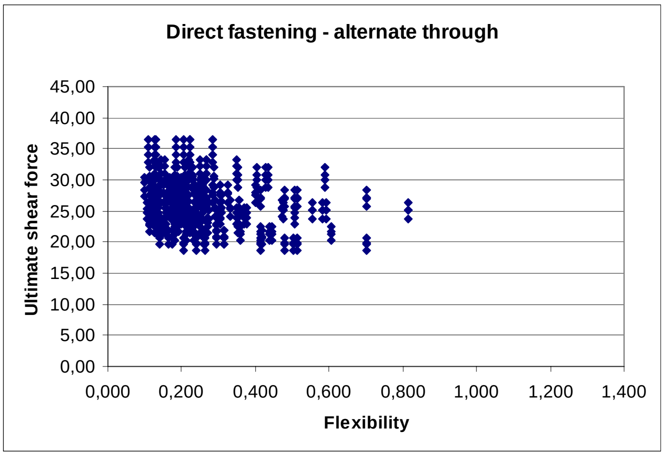

Fig 4.21 relation ultimate shear force- flexibility for a shear cell fastened in alternate trough and shear connectors

- The range of flexibilities is from 0.10 to 0.82 mm/KN

- The range of strengths (S) is from 18 KN to 36 KN
- Statistically c=0.27±0.14 mm/KN and S=26±4 KN

The indirect fastening has a different approximation:

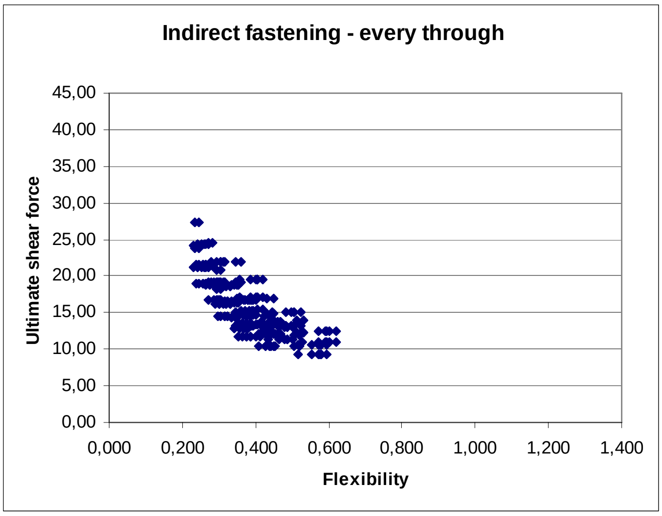

Fig 4.22 relation ultimate shear force- flexibility for a shear cell fastened in every through and without shear connectors

In this case the higher flexibility is associated with a lower strength and a smaller flexibility to a higher strength. The explanation can be that the limiter strength is limited by the seam connection. The higher the number of purlins the higher the resistance and the smaller the flexibility and the other way round.

- The range of flexibilities is from 0.23 to 0.62 mm/KN
- The range of strengths (S) is from 9 KN to 27 KN
- Statistically c=0.23±0.09 mm/KN and S=15±4 KN

The indirect fastening in alternate troughs, mainly for the alternate presents a big dispersion in the flexibilities and a more or less uniform strength.

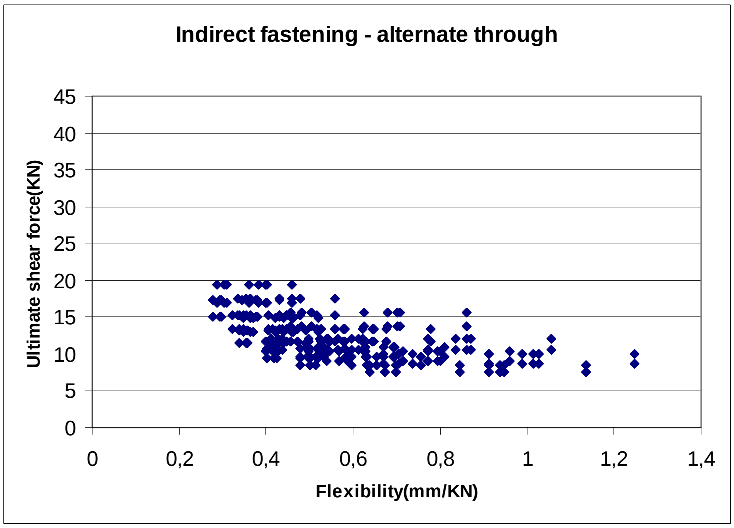

Fig 4.23: relation ultimate shear force- flexibility for a shear cell fastened in alternate through and without shear connectors

- The range of flexibilities is from 0.28 to 1.25 mm/KN
- The range of strengths (S) is from 7 KN to 19 KN
- Statistically c=0.56±0.19 mm/KN and S=12±3 KN

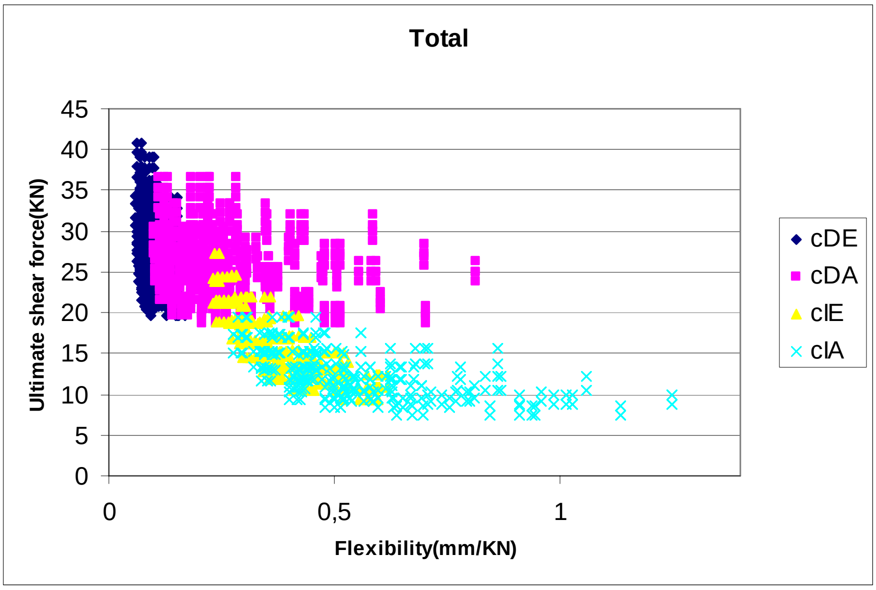

Fig 4.23 relation ultimate shear force- flexibility for a shear cell fastened with the different fastening modus