# Behaviour of Expanded Metal Sheets under Shear Loading

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ABSTRACT

Theoretical study of expanded metal shear panel (EMSP) has shown that EMSP is to be useful in the seismic retrofitting of buildings. Although this product has merit of strength and ductility, it is only used for filters in electrical applications or for the protection of machines (worker's safety) or buildings (anti-intrusion) and it is seldom used for structural applications. There is no guidance existing to help the engineers determine the mechanical properties or to indicate in which field of the structures this product can be used. With the aims at providing some quantitative data and insight for these purposes, this paper describes and compares the results of 16 static and static cyclic experiments of 4 types of expanded metal material in small-scale. These experiments provide useful information. The behaviour of expanded metal sheets (EMSs) is very ductile under monotonic shear loading and stable under quasi-static-cyclic shear loading.

*Keyword:* Expanded Metal, Cyclic behaviour, Cyclic Tests, Hysterical Loops.

## I. INTRODUCTION

Expanded metal is a truss made from metal sheet by cuttings, cold-stretching and flattening [1]. Cuttings and cold-stretching a metal sheet becomes a three-dimension structure. It becomes a two-dimension sheet by flattening. There is neither interlacing nor welding in the elaboration process. An expanded metal sheet (EMS), as shown in Figure 1, has many rhomb-shape stitches. Each rhomb-shape stitch has four bars which are exactly the same dimensions and is geometrically characterized by four diagonal lengths – LD, CD (outer diagonal length), $LD_{in}$, $CD_{in}$ (inner diagonal length), by the width – A and by the thickness of the bar - B. These dimensions are illustrated in Figure 2.

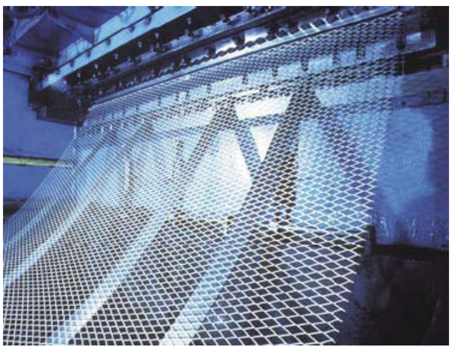

Figure 1 – Fabrication of expanded metal sheets

There are two types of expanded metal product, that is, a normal or standard type and a flattened type. In the normal type, rhomb-shape stitches are connected together by overlapping at the end of each bar. In contrast, there is no overlap between stitches in flattened type. They are continuously connected together to form a completely flattened sheet.

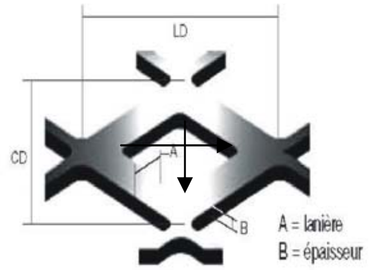


Figure 2 – An expanded metal rhomb-shape stitch

At the moment, expanded metal material is mainly used for filters, in electrical applications or for the protection of machines (worker's safety) or anti-intrusion fences for buildings…etc. Because there are no calculation and mechanical criteria for these types of material, it is seldom used in structural applications.

Some additional considerations have to be taken into account when working with expanded metal. The manufacture of expanded metal truss is not a "refined" technique: tolerances, due to cuttings and cold stretching, are sometimes very large: manufacturers indicate up to 10% on diagonals and bars dimensions. In the same order of ideas, sections of bars are not always perfectly rectangular and, when expanded metal trusses are loaded, some stress concentrations surely occur at the ends of the cuttings. In some cases, tolerances up to 50% have been measured on the section of the bars between the profile catalogue and the real section [1], [2].

The theoretical study of Etienne Pecquet [2] on monotonic behaviour of expanded metal sheets showed that under shear forces EMS behaves like two bands, which are compression and tension bands corresponding to the two diagonals of the sheet. More particularly, in one rhomb-shape stitch under shear forces, there are always two bars subjected to tension forces and the other two subjected to compression forces. Because the thickness of bars, which is also the thickness of EMS, is very small in comparison to the dimension of the sheet, the EMS is always globally buckled under a low shear force. Due to early global buckling, the compression effects on either the overall behaviour of EMS or the local behaviour of bars are always neglected and the EMS work with one tension band developed in post-buckled stages. Assuming that EMS works only in post-buckled stages, a lot of monotonic numerical simulations have been performed on different sizes of sheets, and with different commercial expanded metal profiles. An analytical model has also been developed for EMS under monotonic shear loadings.

Under monotonic loadings, the diagonal tension field actions provide a resistance which can be adequate for lateral resisting systems. However under cyclic loadings equivalent to seismic loadings, the behaviour of EMSs may be different. To provide some quantitative data on behaviour of EMSs, this paper describes 16 tests on four expanded metal profiles: 8 experiments on monotonic loadings and 8 experiments on cyclic loadings.

This experimental study is a part of a research aiming at characterizing the expanded metal material product for structural application, particularly for retrofitting reinforced concrete frames against earthquakes.

## II. REVIEW OF PREVIOUS RESEARCH

In the stages 2005-2008 of the Macro Mousses Project, research work has been done by Etienne Pecquet at University of Liege. One part of the research was about mechanical behaviour of EMSs under monotonic shear loadings. In that study, two approaches, which are analytical models, in-plane and extended-plate models, and numerical simulations, are used and compared to results of experiments on the monotonic behaviour of EMSs under shear loading. Mechanical properties and stress-strain relationship of an expanded metal bar are shown in Table 1 and after doing many tests in tension.

Plane beam elements are used in the in-plane analytical model to determine elastic stiffness of EMSs, the section resistance with the interaction between axial and flexural stresses and the in-plane buckling of individual bars being taken into account.

The extended-plate model, allowing the out of plane instabilities, has been applied for the EMSs as the beam webs with adapting concepts of resistant sections and flexural stiffness of the sheets.

Numerical simulations, performed with FINELG, have used 3D beam elements. Each bar of the truss was modelled as one 3D beam element having seven degrees of freedom at each node. First critical analysis has been performed to obtain global instabilities and initial imperfections and then full nonlinear step by step analysis have been performed.

An analytical model has been adjusted to represent the monotonic behaviour of EMSs. Because of early buckling, the contribution of the sheet to the overall resistance before buckling is always neglected. After buckling a tension band develops along the diagonal direction of the sheets and the sheets work as a rectangular diagonal bar with a certain section area related to the dimensions and types of expanded material. The proposed resistance of a sheet made by expanded metal profile CDxLDxAxB is expressed by:

$$V = 0,27.l_{dia}.\alpha.B.f \qquad \text{(Exp. 1)}$$

Where: V – shear resistance of the sheet
$l_{dia}$ – diagonal length of the sheet
B – Thickness of the sheet – the dimension B of the bar
f – Stress generated in the equivalent diagonal bar

$$\alpha = \frac{A}{l_{bar}} = \frac{A}{\sqrt{\left(\frac{LD-LD_{in}}{2}\right)^2 + \left(\frac{CD-CD_{in}}{2}\right)^2}}$$

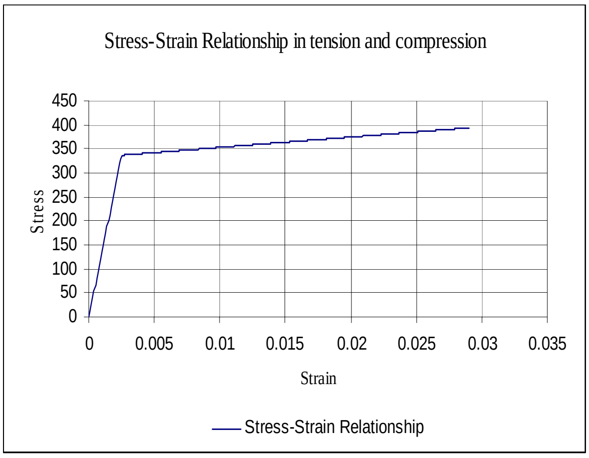


Figure 3 – Stress-strain relationship of an expanded metal bar

## III. DESIGN OF EXPERIMENTS

In order to assess the real behaviour of the EMSs and to compare it to the results of numerical simulations, several considerations had to be taken into account.

First, the experiments have to be designed so that it is possible to reach to ultimate shear resistance of existing commercial expanded metal profiles. For that, all components of experiments are capacity designed to the ultimate shear resistances of all EMSs, as determined by the proposed analytical model [2].

Second, the tests should set forward which one, among two types of EMSs, normal and flattened types, is the most suitable for structural applications.

Third, dimensions of testing sheets have to be taken into account. The standard commercial dimensions of EMSs are approximately about 1250mm x 3000mm. At this stage of the study, it was not necessary to test with the EMS's dimensions greater than commercial dimensions, though the test sheets should have enough stitches of expanded metal truss to obtain the global behaviour of the EMS including not only the resistance but also the instability phenomenon.

Fourth, aiming at obtaining pure shear behaviour of EMSs, the test would be designed so that shear forces from the machine is entirely transmitted to the sheets.

Having accounted for all those considerations, the experiments have been designed. Figure 4 presents the test set up with one of expanded metal panel and the testing boundary frame: the overall dimensions correspond to the centre lines of the framing members, that is a width of 800mm and a length of 1200mm. The EMSs have dimensions about 695x1095mm.

Figure 5 gives a global view of the frame for shear tests in the configuration of the biggest dimensions.

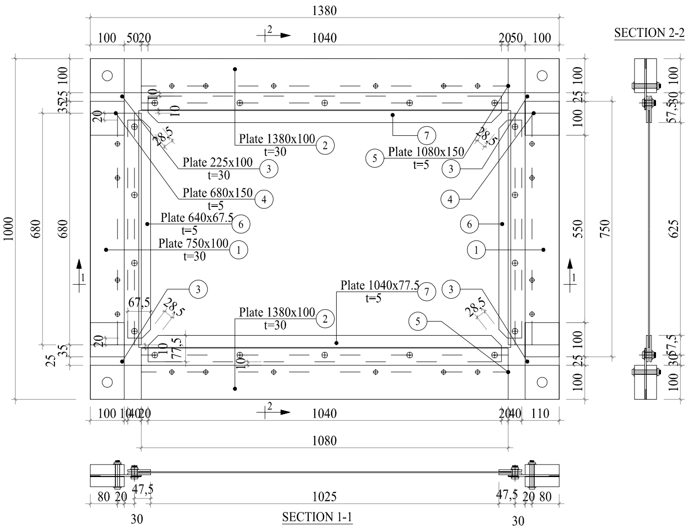


Figure 4– Overall sketch of testing frame

Because the testing frame components are connected together by hinges, the forces which act on the testing frame along diagonal direction are equivalent to the forces acting on the expanded metal sheet. And these forces can be divided into a horizontal and a vertical component. When the axial force is applied at one end of the diagonal, the hinges at the other end of the diagonal freely move. As shown on Figure 6, the axial force on the diagonal of the frame is equivalent to the application of a direct shear force.

The testing machine and the measurement devices are chosen accordingly to the estimated maximum responses of the expanded metal sheets.

Figure 5 – Global view of the frame for shear tests

## IV. DETAILS OF SPECIMENTS

Details of all testing specimens are given in Table 2.

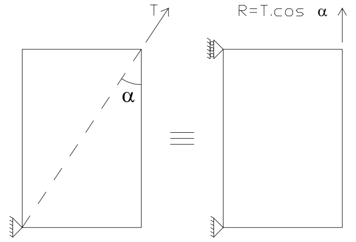


Figure 6 – Loadings on the frame

## V. TEST PROCEDURES

### Monotonic Test

Monotonic test mainly aims at comparing the ultimate shear forces which have been determined by numerical simulations with test results. In addition many properties of specimens are evaluated to provide data for cyclic test phase such as: monotonic force-displacement curve, conventional limit of elastic range: $F_y^+$-conventional yielding force and $e_y^+$-corresponding displacement, and initial stiffness of specimen. The forces acting on the expanded metal specimens are monotonically increased until a complete failure of the specimens will be clearly observed. The displacements which correspond to each step of monotonically increasing forces are recorded simultaneously. Forces and displacements are directly measured by measurement devices which have been attached along to the diagonal of specimens.

### Cyclic Test

Cyclic testing procedure is based on the recommendation of ECCS – 1986 [3] (European Convention for Constructional Steelwork). Cyclic testing phase is divided into two stages. A first stage is a monotonic test used to define the parameters of the cyclic test. A second stage is to test EMS specimens in cyclic loadings. First stage procedures are listed in Table 3.

Second stage could start after having the results from the first stage. In this stage, the EMS specimens will be pulled and pushed successively in many cycles. The tests are run with control displacements. The testing procedure of this stage is presented in Table 4.

Table 1 – Mechanical properties of an expanded metal bar

| Initial Stiffness – Modulus $E_1$(MPa) | Yield Stress (MPa) | Yield Strain (%) | Strain Hardening Modulus ($E_t$) (MPa) | Ultimate Strain (%) | Ultimate Stress (MPa) |
|---|---|---|---|---|---|
| 134000 | 337 | 0.0025 | 2139 | 0.029 | 393 |

Table 2 – Details of all testing specimens

| Specimens | Types | LD (mm) | CD (mm) | A (mm) | B (mm) | Erection Directions |
|---|---|---|---|---|---|---|
| 1 | Flattened | 51 | 27 | 3.5 | 3.0 | LD parallel to short side of the testing frame |
| 2 | Flattened | 51 | 27 | 3.5 | 3.0 | CD parallel to short side of the testing frame |
| 3 | Flattened | 86 | 46 | 4.3 | 3.0 | LD parallel to short side of the testing frame |
| 4 | Flattened | 86 | 46 | 4.3 | 3.0 | CD parallel to short side of the testing frame |
| 5 | Normal | 51 | 23 | 3.2 | 3.0 | LD parallel to short side of the testing frame |
| 6 | Normal | 51 | 23 | 3.2 | 3.0 | CD parallel to short side of the testing frame |
| 7 | Normal | 86 | 40 | 3.2 | 3.0 | LD parallel to short side of the testing frame |
| 8 | Normal | 86 | 40 | 3.2 | 3.0 | CD parallel to short side of the testing frame |

Table 3 – Calibrating monotonic tests

| Step | Descriptions |
|---|---|
| 1 | Evaluating the tangent at the origin of the Force-displacement curve; it gives a tangent modulus $E_t^+ = \tan(\alpha_y^+)$ |
| 2 | Locating the tangent that has a slope of $\frac{E_t^+}{10}$ |
| 3 | Defining the level of $F_y^+$ which is the intersection of the two tangents |
| 4 | Determining the value of $e_y^+$ which is the displacement corresponding to that intersection |

Table 4 – Cyclic testing procedures

| Steps | Applied displacements in tension | Applied displacements in compression | Number of cycles |
|---|---|---|---|
| 1 | $e_y^+/4$ | $e_y^-/4$ | 1 |
| 2 | $2*e_y^+/4$ | $2*e_y^-/4$ | 1 |
| 3 | $3*e_y^+/4$ | $3*e_y^-/4$ | 1 |
| 4 | $e_y^+$ | $-e_y^+$ | 1 |
| 5 | $2*e_y^+$ | $-2*e_y^+$ | 3 |
| >=6 | $(2+2n)e_y^+$ | $-(2+2n)e_y^+$ | 3 |

## VI. EXPERIMENTAL OBSERVATIONS

### Monotonic Test Phase

**General features:**

Under monotonic loadings, the behaviour of all testing specimens can be divided into an elastic stage and a plastic stage. The elastic range starts from the beginning of a test until reaching yield displacement. These yield deformations of all specimens range from 0.85mm (0.12% drift) to 1.17mm (0.18% drift) as shown in Table 5. Beyond the elastic range, all the EMSs perform plastic deformations until attaining ultimate displacements. During the plastic deformations the section area of bars reduces and the slope of force-displacement curves decreases.

There are four couples of two similar tested EMSs in eight testing specimens. In a couple, the expanded metal profile is the same. They are different in the way of setting up to the testing frame as shown in Table 2. Because of this difference, the values of yield displacements, yield force, ultimate displacements and ultimate shear force of each specimen in each couple are slightly different.

In all the specimens, there are some discrete positions which have had visible out-of-plane deformations. These initial buckling deformations are different in each specimen. They become clearer after rather low shear forces are applied. The shapes of buckling waves, as shown in Figure 7, are the same for all testing EMSs. Although the sheets are prone to global buckling, there is no buckle of individual bar observed from the beginning to the end of the test.

Figure 7 – Buckling shape after testing of specimens

The first broken bars observed in all tests are located at the diagonal corners opposite to the force application points of the testing frame. The section areas of these bars clearly decrease before being broken. In spite of the fact that some bars are broken, the sheets keep carrying shear forces. It is also observed that after each bar is broken the shear force is suddenly reduced and then increased until the sheets are completely broken. The broken bars first appear at the corners of the testing frame, then spread gradually to the centre of the sheets.

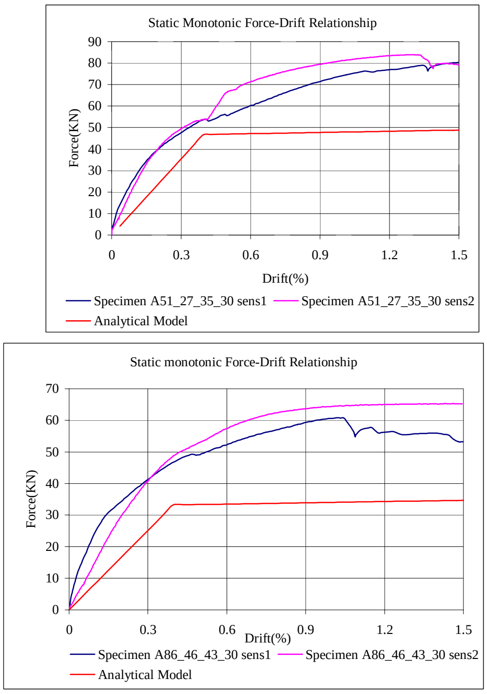


Figure 8 – Force–drift curve in monotonic tests of flattened types and analytical model

All the tests are stopped because EMSs have been largely deformed. There is no failure either at the weld connections between the expanded metal sheets and the plates or at the bolt connections between sheet-plates and intermediate-plates.

**Particular features:**

Out of the two material types of tested specimens, the normal type buckles more rapidly than the flattened type. The shear forces causing buckling in normal type specimens are lower than in flattened types. In each expanded metal type, the ultimate shear forces are proportional to the section area of bars and inversely proportional to the voids of the sheets. The initial stiffness of normal types is much lower than that of flattened types.

Although ultimate shear forces in normal type specimens are less than those in flattened types, the corresponding displacements in normal types are much greater than that in flattened types. Apparently, normal type specimens are more ductile than flattened type specimens. Ductility factors of normal types are twice greater than those of flattened types.

Figure 8 and Figure 9 show the relationships between forces and drifts in monotonic tests in comparison with the analytical model of two expanded metal types.

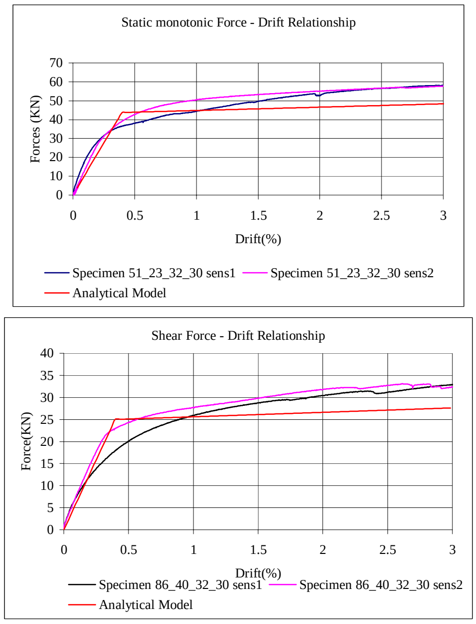


Figure 9 – Force–drift curves in monotonic tests of normal types and analytical model

**Cyclic Test Phase**

**General features:**

All specimens behave elastically in first four cycles until reaching a yield displacement which is also nearly the same as the yield displacements in monotonic tests. In the elastic range, the behaviour of all specimens is not completely symmetric. Beyond elastic ranges when the displacements become larger the hysteric loops are more symmetric.

Initial out of plane deformations are observed in all specimens before testing. In some specimens, these phenomena become clearer after low shear forces are applied to the sheets. Out of plane deflections of the sheets become larger in successive cycles.

In monotonic tests, there is no instability of individual bar. However, in cyclic tests, instability phenomena of bars are clearly observed in all specimens in the plastic range. In addition, the section areas of all the buckled bars are reduced visibly.

Like in monotonic tests, all first broken bars, as shown in Figure 10, are located at four corners of the testing frame and before being broken their section areas are considerably reduced. It is also observed that the crack directions in all cyclic tests start at four corners and then progress to the centre of the sheets to form four crack lines. It is worth noting that, in almost all cyclic tests, the maximum shear force is attained on the cycle on which the first broken bars have appeared.

During first four cycles, the behaviour of the EMSs is linear. From fifth cycle to the end of the tests the shapes of hysteretic behaviour of the EMSs are stable S-shapes. Hysteretic loops in all specimens are characterized by strong pinching. Pinching effects are due to the global instabilities of the EMSs, which cause large degradation in stiffness of the sheets. Like in monotonic tests, tension bands are developed in sheets in every cycle. In addition, because of the pinching effects, before redeveloping new tension band the stiffness of the sheets is approximately equal to zero in the other diagonal.
From the beginning to the end of the tests, there has been no failure either at the weld connections between the expanded metal sheets and the sheet-plates or at the bolt connections between sheet-plates and intermediate-plates.

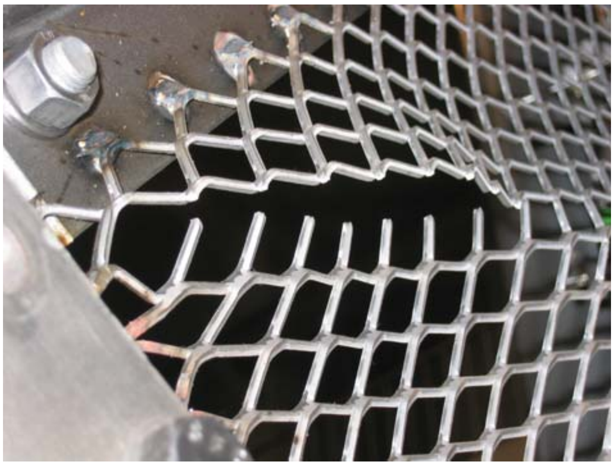

Figure 10 – Crack line and broken bars

**Particular features:**

In monotonic tests, if two specimens have the same profiles but they are different in the way of setting up to the testing frame, their behaviour is not much different. In cyclic tests, their behaviour is very similar in first four cycles. It means that in these cycles, the sheets are in elastic ranges. However, in the plastic range, particularly when reaching the ultimate shear forces or the maximum displacements which are corresponding to ultimate shear forces in monotonic tests, some specimens behave quite differently. The ultimate shear forces and number of hysteretic cycles are quite different from one specimen to another.

As shown in Table 7 and Table 8, the number of cycles in hysteretic behaviour of flattened expanded metal types and the energy which is dissipated are greater than that of normal types.

It is also observed that out of plane deformations at failure of normal type specimens are much greater than those of flattened specimens.

As shown in

Figure 11 and Figure 12, pinching effects on the hysteretic behaviour are much larger for normal type specimens than for flattened type specimens.

## VII. SUMMARY OF OBSERVATIONS

An experimental test program has been carried out on small scale of un-stiffened expanded metal sheet test specimens. The main objectives of the tests was to calibrate the simple analytical model for monotonic shear loading that has been proposed by Etienne Pecquet [2] and to study the hysteretic behaviour of expanded metal sheets subjected to shear.

In both monotonic and cyclic phases of the tests all sheets have buckled at very low shear forces. Some of the specimens (specimens 7 and 8) were globally buckled before testing. Furthermore it was observed that normal types of EMSs, including specimen 5, 6, 7 and 8 (profiles: 51_23_32_30 and 86_40_32_30), buckle more easily than flattened types, which are specimens 1, 2, 3 and 4 (profiles: A51_27_35_30 and A86_46_43_30).

The first broken bars observed in both monotonic and cyclic phases of tests are located near one of four corners, then develop to the centre of the sheets. Additionally it is easy to observe that the broken bars are the bars working in tension. There is no bar being locally buckled in monotonic tests. However, in all cyclic tests, many bars have been buckled before being broken. Moreover, in almost cyclic tests, the maximum shear forces have been attained on the cycle on which first broken bar has been observed.

The maximum shear forces of EMSs in monotonic tests are dependent on the voids of the sheets. With nearly the same voids, ultimate shear forces of flattened type specimens are much greater than those of normal types. Nevertheless, it is observed that maximum displacements of flattened types are much less than those of normal types and the ductility of normal types are much greater than that of flattened types.

The hysteretic loops of all specimens are S-shaped due to pinching effects, but they are stable. The displacement ductility of all specimens is largely different, ranging from 10 to 20. Pinching effects on all specimens due to yielding in tension and to buckling in compression caused the degradation of stiffness of the sheets. In cyclic tests, pinching effects are clear in successive cycles beyond the elastic range. In addition, the magnitude of the buckling deformations and deterioration in stiffness of sheets are increased correspondingly.

In all specimens in cyclic test phases, the stiffness of the sheets is approximately equal to zero during the inversion of force.

Table 5 – Monotonic test results

| Specimens | Yield force (KN) | Yield displacement (mm) | Yield Drift (%) | Initial Stiffness (KN/mm) | Ultimate shear force (KN) | Ultimate displacement (mm) | Ultimate Drift (%) |
|---|---|---|---|---|---|---|---|
| 1 | 33.4 | 1.0 | 0.14 | 33.4 | 78.9 | 9.4 | 1.35 |
| 2 | 32.2 | 1.0 | 0.14 | 32.2 | 83.7 | 8.7 | 1.25 |
| 3 | 27.9 | 0.85 | 0.12 | 32.8 | 60.8 | 7.1 | 1.02 |
| 4 | 25.9 | 1.17 | 0.17 | 22.1 | 65.0 | 8.3 | 1.2 |
| 5 | 27.3 | 1.3 | 0.18 | 21.0 | 60.6 | 25.7 | 3.7 |
| 6 | 18.0 | 0.9 | 0.13 | 20.0 | 57.5 | 20.3 | 2.9 |
| 7 | 9.3 | 0.93 | 0.13 | 10.0 | 31.3 | 15.6 | 2.24 |
| 8 | 10.2 | 0.93 | 0.13 | 11.0 | 32.3 | 15.7 | 2.26 |

Table 6 – First four cycle results

| Specimens | Monotonic yield force (KN) | Monotonic yield displacement (mm) | Monotonic yield Drift (%) | Forces at fourth cycle (KN) | Displacements at fourth cycle (mm) | Drift at fourth cycle (%) |
|---|---|---|---|---|---|---|
| 1 | 33.4 | 1.0 | 0.14 | 30.4 | 1.01 | 0.15 |
| 2 | 32.2 | 1.0 | 0.14 | 31.1 | 1.02 | 0.15 |
| 3 | 27.9 | 0.85 | 0.12 | 20.2 | 0.88 | 0.13 |
| 4 | 25.9 | 1.17 | 0.17 | 24 | 1.10 | 0.15 |
| 5 | 27.3 | 1.3 | 0.18 | 23.4 | 1.01 | 0.15 |
| 6 | 18.0 | 0.9 | 0.13 | 19.0 | 1.00 | 0.15 |
| 7 | 9.3 | 0.93 | 0.13 | 10.1 | 1.20 | 0.17 |
| 8 | 10.2 | 0.93 | 0.13 | 11.0 | 1.29 | 0.19 |

Table 7 – Cyclic testing results at displacements corresponding to ultimate forces in monotonic tests

| Specimens | Monotonic ultimate shear force (KN) | Corresponding displacement (mm) | Corresponding drift (%) | Corresponding shear force (KN) | Displacements at relatively corresponding to monotonic test (mm) | Corresponding drift (%) | Number of cycles (cycles) |
|---|---|---|---|---|---|---|---|
| 1 | 78.9 | 9.4 | 1.35 | 56.0 | 9.8 | 1.41 | 23 |
| 2 | 83.7 | 8.7 | 1.25 | 74.0 | 9.7 | 1.40 | 14 |
| 3 | 60.8 | 7.1 | 1.02 | 42.5 | 8.7 | 1.30 | 20 |
| 4 | 65.0 | 8.3 | 1.2 | 43.3 | 9.3 | 1.34 | 11 |
| 5 | 60.6 | 25.7 | 3.7 | 15.5 | 20.9 | 3.0 | 32 |
| 6 | 57.5 | 20.3 | 2.9 | 40.5 | 20.4 | 3.0 | 12 |
| 7 | 31.3 | 15.6 | 2.24 | 23.2 | 14.5 | 2.1 | 11 |
| 8 | 32.3 | 15.7 | 2.26 | 28.9 | 14.5 | 2.1 | 14 |

Table 8 – Maximum shear forces in cyclic tests and corresponding displacements

| Specimens | Cyclic ultimate shear forces (KN) | Cyclic corresponding displacements (mm) | Cyclic corresponding drifts (%) | Number of cycles (cycles) |
|---|---|---|---|---|
| 1 | 71.6 | 8.3 | 1.2 | 20 |
| 2 | -75.6 | -16.9 | 2.4 | 16 |
| 3 | -48.2 | -20.2 | 2.9 | 26 |
| 4 | -49.3 | -14.8 | 2.1 | 13 |
| 5 | -48 | -7.3 | 1.1 | 14 |
| 6 | -45 | -7 | 1.0 | 10 |
| 7 | 27 | 9.3 | 1.33 | 8 |
| 8 | -28 | -10.8 | 1.56 | 12 |

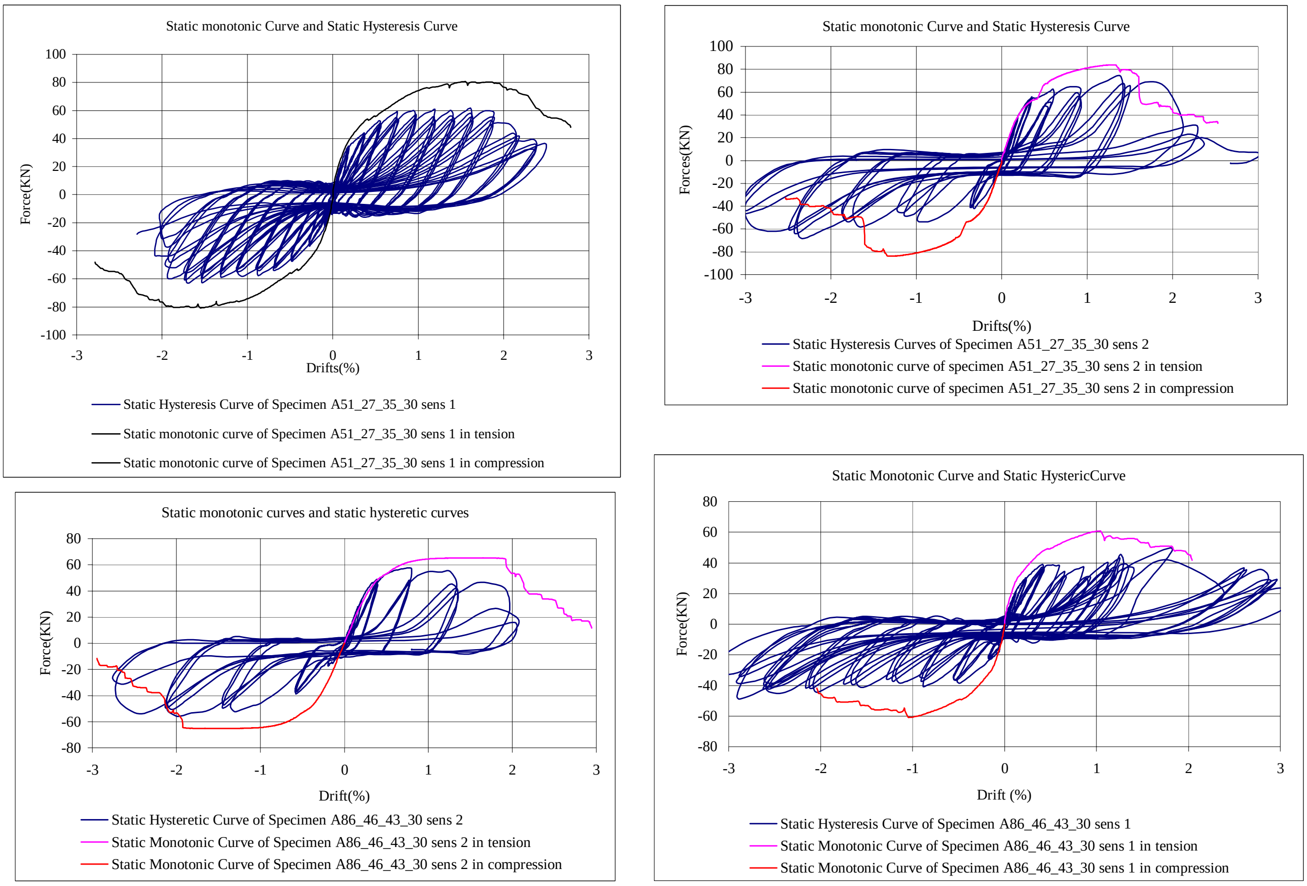


Figure 11 – Hysteretic behaviour of flattened type specimens.

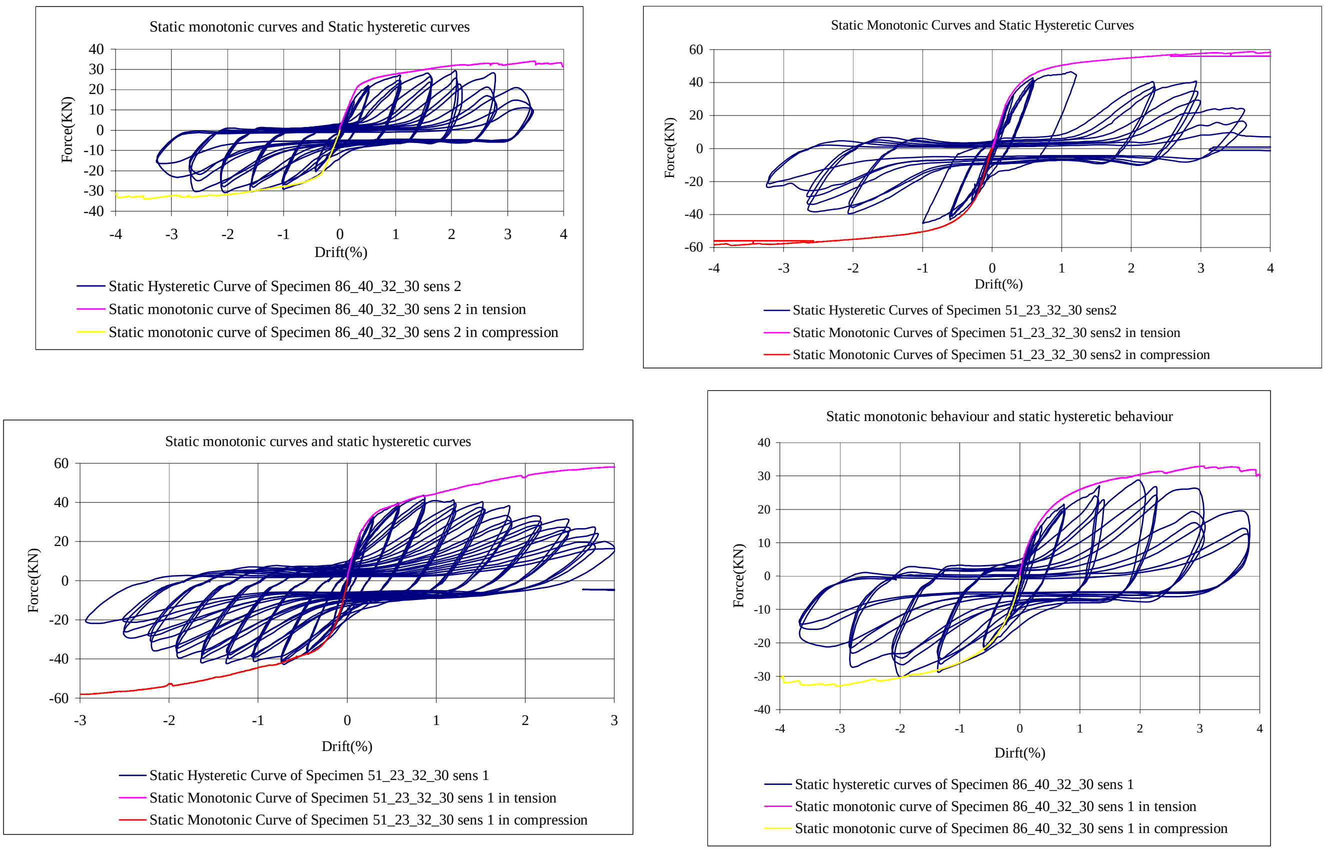


Figure 12 – Hysteretic behaviour of normal type specimens.

## **VIII.** CONCLUSIONS

1. The correlation between the analytical model and monotonic tests varies largely different. In some cases, the analytical model much underestimates the real behaviour of the EMSs. It may be that only one tension band for the monotonic behaviour of the sheets is not enough. The sheets might work in more than one tension band.
2. Because under rather low shear forces the sheets are globally buckled, the contribution of compression diagonal to the resistance of sheets can be neglected.
3. The degradation in stiffness of the sheets due to pinching effects results in a smaller enclosed area under the hysteretic curve and, therefore, a lower amount of energy absorbed by the system during successive cycles.
4. The deflection required to redevelop the tension field is based on the yielding displacements experienced by the sheets on the previous cycles.

## **IX.** PERSPECTIVES

The results of the experiments in small scale specimens described above do not fit in all cases with numerical model and/or analytical formula proposed [2]. This may be due to detrimental effects of weld connections. Furthermore, until now no proposal for hysteretic behaviour of expanded metal material under shear loading has been made.

The next steps of the research on expanded metal material are

1. To improve the analytical model proposed by the study of Etienne Pecquet.
2. To make numerical simulations on expanded metal sheets from small dimension to large dimension of the sheets under cyclic loading and seismic excitations; the simulation should represent the hysteretic behaviour of expanded metal sheets.
3. To make additional cyclic tests in small-scale using other solution for the connection, such as epoxy, glue or butt weld in order.
4. To realise additional tests on large scale expanded metal panel and to check the hysteretic behaviour obtained from the numerical simulations in that case.
5. To model reinforced concrete structures with and without expanded metal shear panels (EMSP).

ACKNOWLEDGEMENTS

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