# Assessment of Shear Capacity of Pre-stressed Hollow Core Floor Units in the Local Construction Industry

P Micallef
Faculty of Architecture and Civil Engineering
University of Malta
June 2005

Pre-stressed, pre-cast hollow core slabs are used as transfer slabs in the local construction industry. The shear capacity of these structural units has a bearing influence on the performance of these elements as such, and is the basis of assessment in this research document. A case study of five manufacturers is undertaken to compare the safety envelope the manufacturers are working in with respect to the shear resistance of pre-stressed hollow core units. Furthermore the safe-load tables of the respective manufacturers are cross-examined with calculations based on EN1992 (2004) and FIP Recommendations (1988). Conclusions are drawn on comparisons between code predictions, test results and declared values by manufacturers for limiting shear forces of individual units.

## INTRODUCTION

The use of pre-cast, pre-stressed hollow core floor units has proven to be a very innovative and efficient element in the local construction industry. The urban development, and more particularly the standard plot layout in piece-meal development, has created a most favourable setting for the use of these pre-stressed hollow core units. The use of these has enabled buildings to have clear, column and beam free spaces on the lower floor areas and dense layouts on the upper floors. Superimposed loads above the level in question are transmitted into a different network of walls/frames supporting the slabs. The panels are designed to carry very large loads. However, as shorter spans are used, the critical failure mode of these elements becomes shear. The section capacity of a panel is specified by the supplier in safe-load tables.

As such, local manufacturers do not adopt a standard or harmonized approach on how to present their safe load tables and this results in a confusion in the interpretation of these tables. The information provided is not adequately explained and there is misunderstanding whether the values provided are applied loads or resisting forces. The tables should lead to an unequivocal measure of strength for the particular product.

The CE marking is not yet mandatory on the local product, however when this will be in force it will be mandatory for the manufacturers to provide comprehensive technical documentation of the product at hand. The CE marking as such signifies that a product is in conformity with the standard stated by the Eurocodes or with a notified standard. The CE certified product must be traceable back to its raw materials. The labelling requires that properties of the section are declared, either by directly affixing them on the product, or in an accompanied technical documentation. In line with EN13369 (2004) the latter is divided into three categories, relating to production specification, handling and installation specification.

## RESEARCH IN P.C. HOLLOW CORE FLOORS

Research into precast hollow core floors is focused on the comparison of single standalone units to a flooring system (made up of many units) subject to similar loading combinations.

Lundgren & Plos (2004b) analyzed a sample of 30 floors, each consisting of a varying group of slabs. These samples where analyzed using a pre-defined (Lundgren & Plos ,2004a) computer program based on finite element design. Some of the load combinations where assessed in accordance with Annex C of prEN1168 (2004). The analysis showed that a reduction in the torsional moment was obtained in a setup with horizontal restraints. This however has further implications. Rigid supports are highly undesirable as they would be creating restraining forces due to, for example shrinkage and thermal movement within the unit.

The experiment setup for flexural shear carried out by the same authors is similar to the test setup adopted in this research project.

Traditionally, no difference has been made between slabs supported on beams and slabs supported on walls. When loading a floor in which hollow core floor units rest on beams, the slabs and the beams deflect. In such a system, the slabs closer to the columns are subject to both vertical and transverse shear. Tests carried out by Pajari & Koukkari (1998) contradicted the predictions of conventional design since the shear resistance of the hollow core slabs was found to be governed by the deflection of the supporting beam for deflections as small as L/1000.

The shear force was found to be critical for thick, heavily pre-stressed slabs with large voids subject to a high shear force and small bending moment. In most cases the resistances obtained where relatively low compared with the values observed in traditional shear tests carried out by the same authors. The reductions in shear force resistance varied from 23% to 60% in comparison to the predicted failure load and the deflections observed in the supporting beams could not quantitavely explain the reduction of shear force in the slabs.

. M. Pajari & H. Koukkari (1998) suggest that the reduction in the shear resistance is attributed to the transverse (shear) deformation of the slab ends. Such deformations occur whenever the slabs are resting on beams, irrespective of the type of beams and support conditions. The reductions of these deformations can be obtained by taking into account the deflection of the beam and the interaction between the slab ends and the beams.

## EXPERIMENTAL SETUP

In order to assess the safety envelope of the units being produced locally, it was necessary to build a comparative study; in order to draw on the differences when comparing like with like. Samples where fetched from various manufacturers and the provision of the test slabs was based on the manufacturers' disposition and availability. Samples where obtained courtesy of manufacturers A, B, D, and E though a sample was not readily available from one of the manufacturers at the time of request. The samples consist of one four meter (4m) section from manufacturers A, B, D, and E (a sample was not readily available from one of the manufacturers at the time of request), cut out of a ready cast member.

The grade of the concrete for every sample was determined by extracting cores out of a 200mm section that was provided. This section was cut from the same cast of the four metre samples. 50mm diameter (Ø) cores where drilled parallel to the plane of casting. The samples where drilled in sets of three. In all two sets of cores where taken for each slab; all cores trimmed to a proportion of 1:1

**Figure 5.0:** Test Samples Stacked on site

The test specimen is analyzed under the application of a knife edge load through the width of the slab, located at 575mm from the support (two and a half times the height of the unit). The procedure followed is in accordance with Annex J of prEN1168 (2004). The sample is tested to failure in order to obtain a failure load in such a mode. The failure load for each sample is compared to the respective safe load calculated in **section 4** (Micallef , 2005) and load deflection graphs are drawn up to assess the mode of failure and for comparison purposes.

The loading procedure consisted of repeated loading in ten (10) cycles. The magnitude of the loading of the first 9 cycles was contained within a 70% margin of the expected failure load. During the last cycle, the test sample was tested to failure and the ultimate load recorded. In all cases, the speed of loading of the element did not exceed 10% of the expected ultimate load per minute. The load was applied through a 600KN hydraulic jack.

The test program consisted of four series of tests, equivalent to one series for every manufacturer A, B, D, and E. Each series consisted of two tests(series $1/00_n$ & series $2/00_n$), one for every end of the slab.

**Figure 1:** Layout of test sample

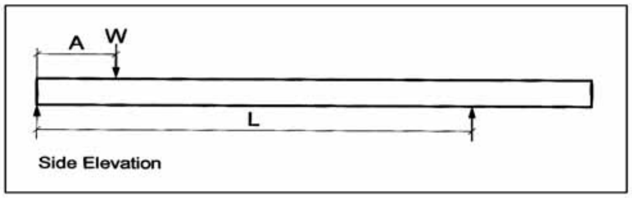


**Figure 2:** Typical Experimental Setup

## RESULTS

Cores where required to analyze the concrete properties of the samples and to extrapolate the magnitude of the compressive strength of each slab. The cores where measured, analyzed and finally crushed in a compression machine.

Under visual inspection, it was noted that the aggregate used in all concretes is very flaky and very weak. The pore structure in the surfaces of the exposed aggregate could be seen under the naked eye, suggesting that the material is very porous. The aggregate is the only constituent of the concrete that is produced locally. All the other constituents are imported. It is evident that better workability results are obtained when the extrusion process is adopted in production, as compared to samples obtained from slabs cast by slip-forming. Blow holes where more frequently noticed in cores that where tcast in a concrete section result from poor workability.

After crushing the cores, the failed cylinders where analyzed and it was evident that in all the samples, the splitting of the concrete happened through the aggregate rather than through the cement matrix. This result highlights the weakness of the aggregate. It is specified that local producers should quarry hard stone in order to have the highest quality aggregate available in production, however since the formation of rock is a naturally occurring phenomenon, the quality of the stone in use is not always guaranteed. Hence the aggregate is a weak link in the local production of concrete.

The load - displacement graphs resulting from the experiments compared well with previous research carried out by Pajari & Koukkari (1998) and Lundgren & Plos (2004b). No crack propagation was noted before failure and the slabs failed suddenly when the failure load was reached.

**Figure 3:** Typical Post-failure Cracks recorded at front face

The way in which failure developed in series D and E was optimal because the crack pattern was in such a way that the whole section was working together at resisting the shear forces within it. This indicates that the properties of the unit are even throughout and when loaded, the unit acts like a singular element. On the other hand, crack patterns in samples A and B show that the slabs failed at weak points. It was noted that the slabs with the larger webs where more prone to this random cracking.

For comparison purposes, all the loads where converted to shear forces in the samples. Two plots of combined shear force against displacement where plotted; one for every test, denoted here as **chart 6.9** and **chart 6.10** respectively.

The code predictions and the declared safe shear load (safe-load tables) where plotted on the same graph in order to better assess the results. The code prediction provides resistive shear values, whilst the values for shear force where selected from the safe load tables. The graphs representing the code predictions (EN1992-1-1, 2004) and the safe shear from the safe-load tables where drawn as horizontal plot lines, with a y-intercept equal to the predicted and quoted shear resistance respectively. In all cases it was recorded that the calculated shear resistance in the zone uncracked in flexure, deduced by EN1992-1-1 (2004) was larger than the limiting shear force quoted in the safe load tables and smaller than the shear resistances recorded during experimentation.

A pattern was noted with respect to results of series B, D, and E. In both charts, the lower bound failure is attributed to series E, followed by Series D and Series B. The results of series A are not consistent to this pattern. In **chart 6.9** the failure load of Test A110 falls between the results obtained from D110 and B110 whilst in **chart 6.10**, the failure load of A210 is the highest peak noted in all experiments.

**Table 6.2** summary of the results obtained through testing.

| Series | A | B | D | E |
|---|---|---|---|---|
| **Series 1/10 Critical Shear (KN)** | 192 | 213 | 200 | 136 |
| **Series 2/10 Critical Shear (KN)** | 243 | 215 | 183 | 115 |
| **Average Test Critical Shear (KN)** | 217 | 214 | 192 | 125 |
| **Code Prediction (KN)** | 171 | 190 | 160 | 73 |
| **Safe Load Tables Safe Shear (KN)** | 160 | 115 | 115 | 40 |
| **$b_{eff}/b$** | 0.43 | 0.43 | 0.43 | 0.26 |
| **Test Load / Code Prediction** | 1.27 | 1.13 | 1.20 | 1.72 |
| **Test Shear/ Safe Load** | 2.72 | 3.72 | 3.33 | 6.28 |
| **Code Prediction /Safe Shear** | 2.14 | 3.30 | 2.78 | 3.65 |

**Chart 6.9: Combined Shear Force Vs Displacement Graphs**

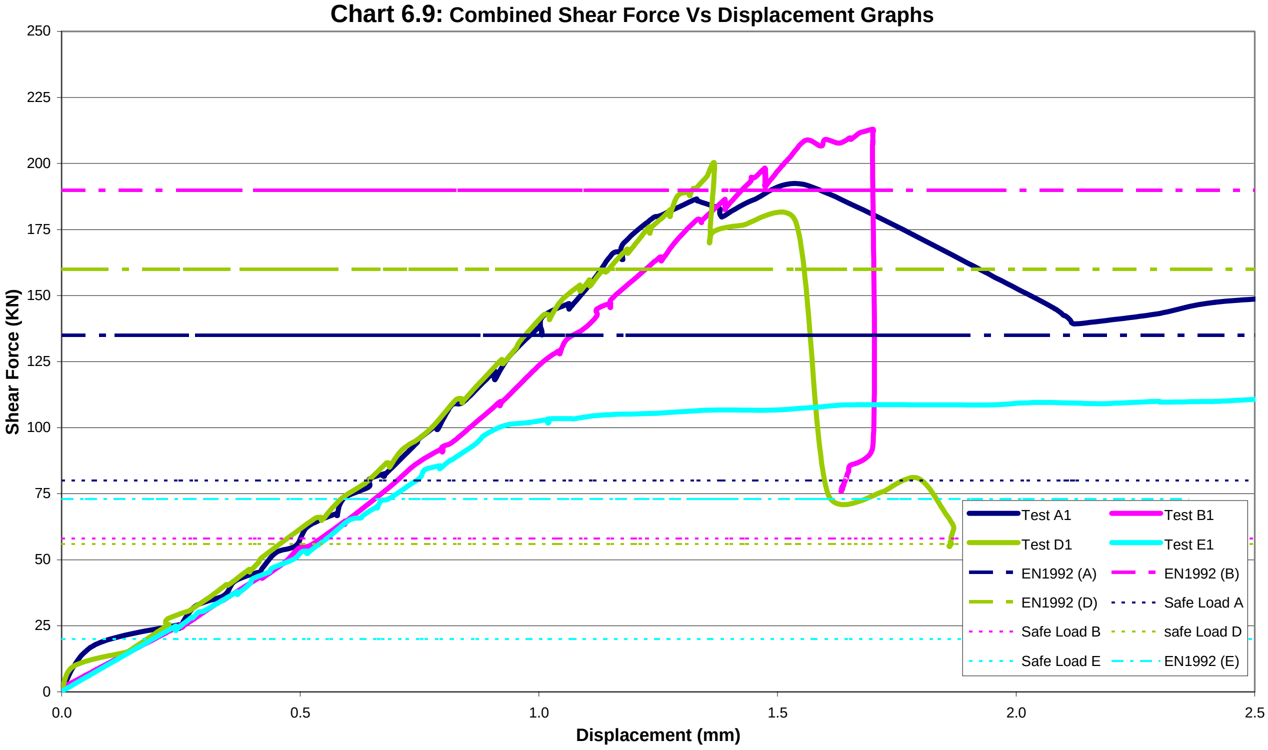


**Chart 6.10:** Combined Shear Force Vs Displacement Graphs

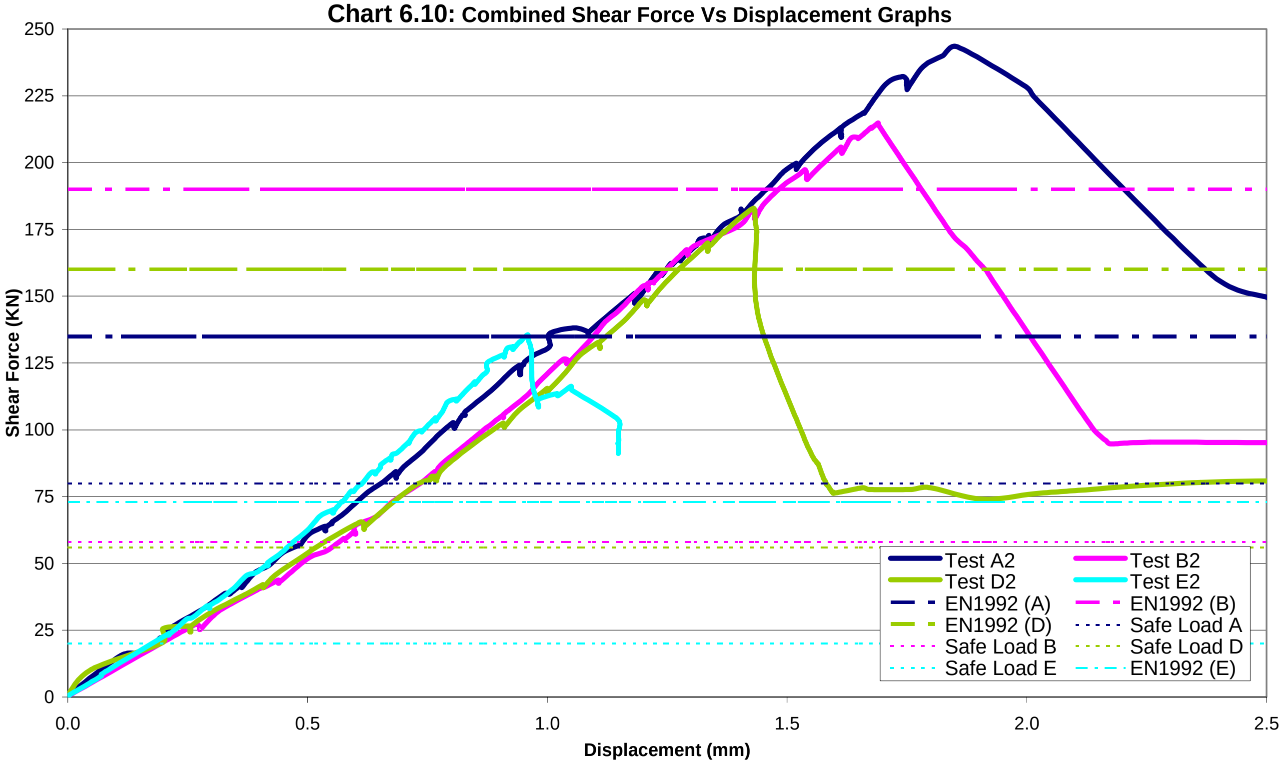
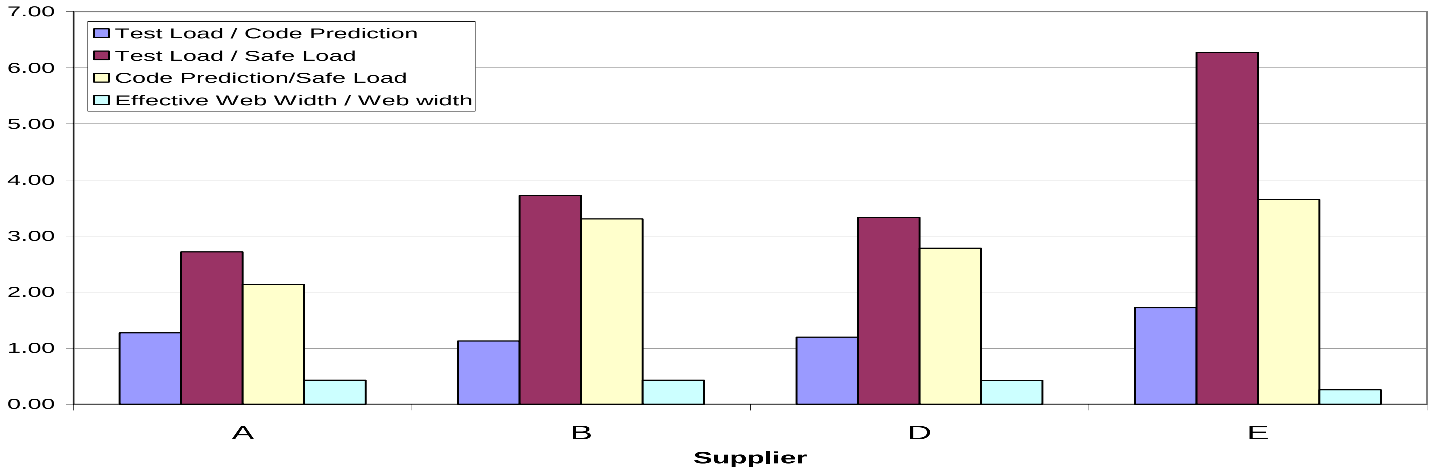


**Chart 6.11:** Comparative Study



## CONCLUSIONS

The research carried out shows that there is a big confusion in the provision of data in the safe load tables mainly due to the miss-interpretation of values given in these same tables. After consulting the respective structural consultants responsible in formulating the local safe-load tables, it was found that some manufacturers quoted ‘safe shear’ as a measure of the resisting shear force at the support of the unit, whilst other suppliers quoted ‘safe shear’ as a measure of allowable superimposed load; both quantities being quoted in measures of KN.

The safe shear is the resistance of the slab to shear failure (resisting shear at the support) whilst the safe load in shear is that limiting load that will cause the slab to fail in shear. Furthermore, with the introduction of the CE marking it will be mandatory for the manufacturers to quote properties relating to the geometry and performance of the product as well as its constituents.

The codes as such underestimate the actual tensile strength of concrete since the use of admixtures in the concrete mix is not taken account of in the formulation of the design tensile strength. The code prediction for tensile shear could be better enhanced if the tensile strength of the concrete where calculated in a more direct manner. S. Desai (2003) reports gains in tensile strength of up to 10%, when using direct test methods and analyzing concretes that differ from Portland cement.

The increase of the web width in the cross-section of the units is found to have a beneficial effect on the shear carrying capacity of the slabs. Considering that the applied prestress force, the amount of steel put into the cross-section and the concrete grade of the different samples are similar within reasonable limits, the larger recorded strengths in samples A,B and D over sample E show that different sections can have a beneficial effect to the properties of the unit. However the high failure load obtained in experiment A210 cannot be explained. Furthermore, in sample B the increase in concrete cross-section was notable over the other samples, though the increase in the web widths was only marginal because most of the material was concentrated in the flanges. Hence the distribution of the concrete in the section is not optimal.

The tests undertaken are not conclusive because the number of samples tested was far too little to draw definitive conclusions. However, the results suggest that the trend in the industry is to apply large safety factors in the values quoted in the safe load tables. It would be more reasonable if the values in the tables where to be brought closer to the actual predictions of the code. Such an option will be even more feasible when the CE marking is introduced in the local market.

## RECOMMENDATIONS

Further research should be carried out on a larger sample such that conclusions are drawn on statistical data. Investigations on locally produced slabs should be oriented on the basic requirements stipulated in prEN1168 (2004). Such information on the local product is not available at the moment.

Furthermore, the shear interaction in prestressed hollow core slabs resting on beams should be investigated. Similar research carried out by M. Pajari & H. Koukkari (1998) showed that with very small deflections of the primary beams, the shear capacity of prestressed hollow core slabs was reduced considerably. This could have many repercussions in the local construction industry and research into this field should be undertaken.

## REFERENCES

Desai S, (2003), ‘Influence of constituents of concrete on its tensile strength and shear carrying capacity’. Magazine of concrete research, 55, No. 1, 77-84

Lundgren K & M. Plos (2004a), ‘Shear and torsion interaction in hollow core slabs’. CHALMERS, Structural Engineering and Mechanics, Report no. 04:04

Lundgren K. & Plos M. (2004b), ‘Shear and torsion interaction in hollow core slabs’. CHALMERS, Structural Engineering & Mechanics, Report no. 04 : 7

Micallef P., (2005), ‘Assessment of Shear Capacity of Pre-stressed Hollow Core Floor Units in the Local Construction Industry’, University of Malta.

Pajari M & Koukkari H, (1998) ‘Shear resistance of PHC slabs supported on beams I: Tests’. Journal of structural engineering, No. 9, 1050-1061