Experimental Study of Vertical Deflection on Bracket-Angle Stainless Steel Masonry Support Systems

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ABSTRACT: Stainless steel masonry support systems have been tested in order to determine actual deflection under loading. The type of system tested is a Bracket – Angle system produced by IG Masonry Support Systems Ltd. Despite this being one of the most common and most used systems in the masonry support sector, very limited research on this behaviour has been conducted. Displacement transducers are placed in specific locations in order to record actual deflection of the system at every increment of loading. Multiple transducers have been used in order to determine the contribution of each part of the system to deflection. A mathematical approach has also been developed and tested to determine if accurate estimation of deflection is possible. All tests results are consistent, and the mathematical approach proved to be accurate and able to adapt to all the different situations tested.

KEY WORDS: Load-deflection behaviour; Load testing; LVDTs, Masonry support systems; Stainless steel; Veale's theory.

1 INTRODUCTION

Masonry cavity walls are a widely used construction solution, especially in the UK. A cavity wall is usually composed by a load bearing wall and a masonry wall, separated by a continuous air space which provides insulation to the building.

Generally, the performance of a masonry support system is defined by many factors: ease to install, low stress, low deflection, low transfer of heat, possibility to cover bigger cavities etc.

The most critical features though are stress and deflection, which directly depend on the geometry of the system and thickness of steel. Unfortunately, investigation on these kinds of products is limited, mainly because of the absence of design regulations and the practical difficulty of determining those values.

1.1 Aims and Objectives

The current study focused on welded Bracket-Angle systems. The general objective was to increase the knowledge on these kinds of systems by investigating IG Masonry Support products. The final scope was to write theoretical rules capable to make accurate deductions for stress and deflection of the whole system.

Theoretical results were obtained through structural design calculations and Finite Element Modelling (Solid-Works). Over one hundred vertical loading tests of IG Masonry Support Systems products have been conducted.

1.2 Background and Previous Research

Previous theoretical studies were conducted by J. R. Veale [1], [2]. In the first publication in 1988 [1], the author described a "structural design procedure" for masonry support angles. The author suggested a method of analysis which put emphasis on the "effect of the fixing spacing on the size of angle"; aspect that he considered very important and too much neglected. Up until Veale's theory, it was usually assumed that the horizontal leg of the angle acted as a cantilever subjected to a "*uniform line load*". This takes no account of the fixing spacing and the fact that conditions on the angle are not uniform since the stress is higher at the fixing/welded positions than elsewhere.

In 2003, Veale published a review of his first document implementing his theory and considering the "Design Method" for Stainless Steel Angles for Masonry Support suggested by The Steel Construction Institute [3]. In the author's last publication, Veale states conclusively that "The assumption of uniformly distributed loading is clearly unsafe" (referring to simple masonry support angles). In both of the documents by this author, it is highlighted how "Particular consideration must be given to the fixings span, continuity of the angle, arching action in the masonry and the stiffness of the fixing details". In February 2017, IG had the pleasure to meet with J. R. Veale and discuss not only his theory but also the improvement of the masonry support industry over the years.

The most significant difference between this study and the one conducted by J. R. Veale concerns the interaction between the brackets and the angles. Brackets were indeed not very common before 1994 and that's why Veale mainly focused on simple angle systems. The author agreed with the importance of the bracket-angle interaction (which reflects the "stiffness" of the fixing for the angle).

Veale also confirmed he is not aware of any company or laboratory that has ever tested his theory and he himself never had the opportunity to do it. In the conclusions of his paper indeed he highly suggested a comparison with other ways of analysis and, more important, with experimental data and structural testing.

2 TEST FRAME, MACHINERY AND MATERIALS

2.1 Test Frame

IG Masonry Support Ltd (IGMSS) is part of "The Keystone Group", the UK's largest Steel Lintel manufacturer. During the years, IG performed different tests on bracket-angle systems using a “proprietary” Test Rig (Figure 1) designed with the help of Queen’s University Belfast.

Figure 1. IGMSS Test Rig.

The previous design consisted of a two-point loading on the shelf angle where the brackets are bolted to a steel beam. This way of testing is based on the historical assumption of funnelling of masonry, making these two points the most loaded points on the shelf. Even if this statement can be considered correct and matches with scientific tests conducted on masonry, it does not take into account the Bracket-Angle system response to loading.

According to Veale’s theory indeed, the angle stiffness under the vertical load is greater at each support than at mid span, leading to the idea that the “*uniformly distributed load assumption is not accurate*” and instead, the load distribution is better “*represented by a Fourier series*”. The idea to consider the horizontal part of the angle as a cantilever indeed is based on the assumption that the vertical part of the angle remains perfectly vertical even after loading. Tests have proved this is not what really happens. This model is in fact more complicated but more accurate because it takes into account the twisting of the angle along the longitudinal axis.

In order to best recreate the real situation, IG designed a new test frame, again with the aid of Queen’s University Belfast. This new test frame is designed to load the shelf uniformly by exploiting a “load spreading device” in order to spread the load on the entire shelf angle. In this way the whole shelf is loaded allowing for it to twist. Another difference from the previous design concerns the way of fixing of the rig to the ground. As it’s possible to notice in Figure 1, the steel beam is not fixed to the ground, but it’s fixed to a steel structure which is connected to the ground. Even if the dial gauge used to measure the deflection is attached to the beam, reducing any possible aberration, part of the load and the stress which should be sustained only by the fixings and by the bracket, might be “absorbed” by the torqueing of the steel beam. In order to avoid this situation in the new test frame, the steel rig base is fixed to the ground (bolted). The steel beam is fixed to the base using mechanical fixings. The entire main frame is made of 10/12 mm thickness of steel. The main beam is a rectangular hollow section. No channel sections were used in order to reduce torqueing and movements of the rig.

2.2 *Machinery*

The loading machine is an Electro Hydraulic testing machine with a capability of compression testing up to 600 kN. It operates a closed loop system, controlled electronically. When the controller registers a command, signals are sent to move the ram and feedback signals from load and displacement sensors then tell the controller where the ram is at any point in time. The controller then can decide how to move next. The displacement transducers are linear variable displacement transducers (LVDTs) and two different sizes were used; 50 mm and 100 mm.

2.3 *Materials*

Fixing materials: Standard Stainless Steel fixing bolts were used. A calibrated Torque Wrench has been used and the fixing manufacturer’s specifications have been followed.
Load spreading device: The use of this device is to equally spread the load on the shelf.
Damp sand: During the initial test phase the use of damp sand has been tried in order to recreate mortar. Further studies proved the effect of damp sand is negligible.
Brackets and Shelf: All the masonry support products are proprietary systems of IG Masonry Support Systems. Steel thickness and geometry change based on design load of each specimen.

3 TEST PROCEDURE

This masonry support system study is aimed to determine the deflection at design load and the capacity of each system.

The Welded Masonry support units are fixed to the backing steel frame. The standard 2 mm shimming is normally used. In a real masonry wall construction, every 300 mm wall ties are used to prevent the wall from bending after the normal initial deflection of the shelf. In order to guarantee perfect horizontal position of both shelf and load spreading devices, constant checks are performed with a level both before and during the tests till failure is reached. Once the masonry support system is properly fixed to the backing structure, all the LVDTs are placed in position.

4 No. LVDTs are placed under the shelf and 1 No. under the bracket. LVDT number 2 (G.2) is placed at mid-span of the angle. The shelf is indeed supposed to be weaker at this point and the biggest deflection is expected here. In line with G.2, two other LVDTs are placed: G.3 and G.4. G.4 is also aligned with the bracket external wall; at this point the shelf is expected to be stiffer. G.3 is placed halfway in between G.2 and G.4. The LVDT under the bracket, G.5, is placed at the very end of the bracket external wall and hence in line with G.4.

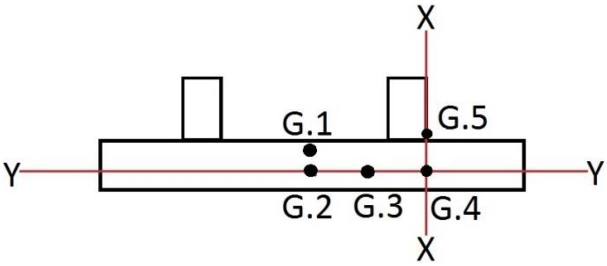

Figure 2. Deflection measurement: LVDT positions.

According to EN 846-10:2000 [7], a preload of 1 kN is applied and held for 1 min. This allows for the fixings and the system to settle before the continuous loading starts. The load is applied vertically through a hydraulic ram and increased continuously by 0.5 kN steps up to the maximum expected test load or design load. Once the maximum expected load is reached, the loading is gradually reduced, while data recording doesn't stop. By gradually reducing the load, the recovery of the material can be evaluated and additional information on the elastic limit of the steel can be gained.

3.1 Failure mechanisms

In masonry support systems there are different ways a system can fail, as follows;

Fixing failure: this is not very a common fail, especially in steel, but the fixing capacity is a limiting factor most of the time. Fixing failure has never been experienced during testing.

Welding failure: This is not a very common failure mechanism either but it must be kept in mind that the load is transmitted from the shelf to the brackets through the welds. The failure of the whole system would be immediate. During testing this kind of failure has never been encountered. BS EN 1993-1-8:2005 [9] rules on welds specifications have been carefully followed.

Deflection failure: This situation happens when the system reaches the limit set as maximum allowable deflection. This is the most common type of failure in masonry support systems.

Lock Washer failure: The Lock Washer (LW) is one of the most important parts of the whole system. It allows for vertical adjustability and transfers the load from the bracket-angle system to the fixing. When the load on the shelf is too high, well over the design load, the LW wings can fail and thereby bend too much, pulling through the bracket with a consequent failure of the overall system.

4 DISCUSSION OF RESULTS

In this paper the original results are presented in the clearest way possible considering that some of the figures are covered by a non-disclosure agreement between IG Masonry Support Systems and Queen's University Belfast. It is also important to underline that the objective of this research was to generate reliable theoretical calculations which are able to predict stress and deflection of each type of system.

Table 1 lists the deflections detected at mid-span for each type of system tested. Mid-span is assumed to be the point with the highest deflection. Tests proved this assumption to be correct. Only the first figure of the numbers is displayed due to a non-disclosure agreement.

All the tests showed that thickness of material is one of the most important properties, but the geometry of the system proved to be crucial as well.

It is important to stress that the thickness of steel can vary from one system to another. Testing proved that two systems that are designed to carry the same load, with same shelf and bracket thickness but different geometry can have very different results.

Table 1. Deflection for systems tested.

Load [kN/m]	Shelf length [mm]	Cavity [mm]	Deflection [mm]
12	990	150	2.- -
12	990	100	2.- -
12	990	150	2.- -
12	590	200	3.- -
12	590	200	2.- -
12	990	50	1.- -
12	990	150	2.- -
12	990	150	3.- -
12	990	150	3.- -

4.1 Deflection contributions

The deflections shown in Table 1 are assumed to represent the sum of all the different deflection contributions that occur in the system at midspan i.e. from bracket, LW and shelf. Each one of these components contributes in part to the total deflection.

Figure 2 shows how the LVDTs were placed in position for testing. Two main axes were considered here as indicated in this figure; X-X and Y-Y.

G.2 – G.3 – G.4 are along the Y-Y axis while G.5 and G.4 are on the X-X axis. G.4 falls on the intersection of the two lines. This type of layout allows splitting of the two main shelf behaviours: cantilever behaviour and simply supported beam behaviour. Analysing the measurement points on the Y-Y axis, it was observed that the highest deflection was detected by G.2, followed by G.3 and G.4 respectively, proving that the parts of the shelf closer to the brackets are stiffer. On the other hand, G.4 detects a deflection even if it corresponds to a fixing. This shouldn't happen in correspondence of one of the two supports of a normal beam. The logical consequence is that the deflection of the points on Y-Y line depends on two factors: simply supported beam behaviour and cantilever behaviour. Tests also proved that the closer the two brackets are, the less deflection there is. This happens because when the brackets are far from each other, the beam behaviour is predominant and the cantilever deflection component is negligible. The closer the brackets are, the more predominant the cantilever behaviour is. Ideally if the two brackets were at zero distance there would only be a simple cantilever deflection.

J. R. Veale's theory was then correct [1,2]; a simply cantilever behaviour assumption is wrong as it doesn't take into account the two supports of the shelf. His theory to predict the shelf deflection based on Fourier series proved to be quite accurate.

As outlined earlier, Veale's theory only concerns the shelf deflection without considering any other contribution (i.e. brackets). The deflection theory utilised here has been expanded in order to cover for bracket-angle systems too. Table 2 presents a comparison between results estimated using this mathematical model, and results obtained from actual tests.

Table 2. Difference between predicted results and test results.

Type of System	Absolute Difference on Bracket [mm]	Absolute Difference on Shelf [mm]
(12) 990/150	0.08	0.04
(12) 990/100	0.07	0.13
(12) 990/150	0.10	0.13
(12) 590/200	0.12	0.21
(12) 590/200	0.29	0.11
(12) 990/50	0.07	0.07
(12) 990/49	/	0.07
(12) 990/150	0.04	0.04
(12) 990/150	0.16	0.03

The "cantilever" behaviour is better highlighted on the X-X axis only for what concerns the shelf. Tests indeed proved that the bracket behaviour is far from simple cantilever behaviour. Simple cantilever beam calculations and Finite Element Modelling would suggest a deflection on the bracket that is very different from the actual deflection detected during the tests.

After careful studies it's been proven that the brackets suffer from a buckling effect, which increases the deflection tremendously. Simple cantilever theories cannot translate this behaviour and for this reason an experimentally derived calibration factor has been introduced, which allows prediction of the bracket deflection in a more accurate way.

4.2 *Mathematical model*

The mathematical model on which is based this theory can be explained with the following formula:

$$\delta \propto \sum \alpha\, x_1 + \beta x_2 + \gamma x_3 + \varepsilon x_4 \qquad (1)$$

This formula describes the overall deflection of the complete system as proportional to the sum of each contribution of the system multiplied by an opportune factor. In this case $\alpha, \beta, \gamma, \varepsilon$ are the factors corresponding to the Angle, Bracket, LW, and the contribution given by the buckling of the brackets respectively. All these factors are based on IG products and need to be adapted in order to work with systems based on different geometry.

4.3 *Comparison between mathematical model and test results*

This mathematical model has been applied to all the tests conducted and it proved very accurate. In the following figures it is possible to see the comparison between the predicted deflection using the model and the actual deflection occurred during testing.

Figure 3 represents the prediction at the design load, which is 12 kN/m for all systems tested. However, it is important to underline that the cavity width is not the same for all these systems; it ranges from 49 mm to 290 mm. As can be observed, the range is very comprehensive proving the ability of the model to adapt and cater for every single system specification.

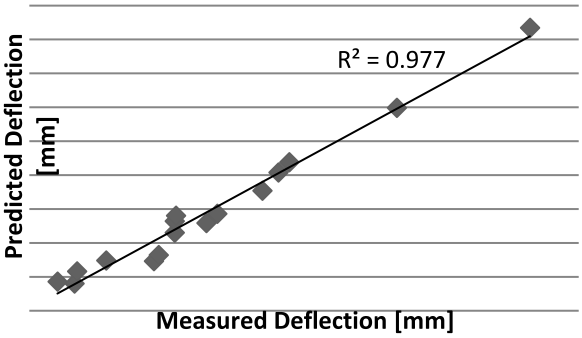

Figure 3. Comparison between theoretical model and actual results – 12 kN/m Design Load.

The following two figures display the predicted deflection compared to measured deflection at different stages of testing. Figure 4 shows data at 4 kN/m i.e. one third of the design load, and Figure 5 shows data at 8 kN/m i.e. two thirds of the design load.

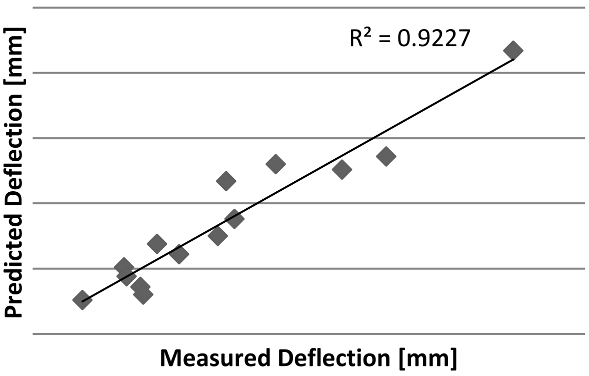

Figure 4. Comparison between theoretical model and actual results – 4 kN/m loading.

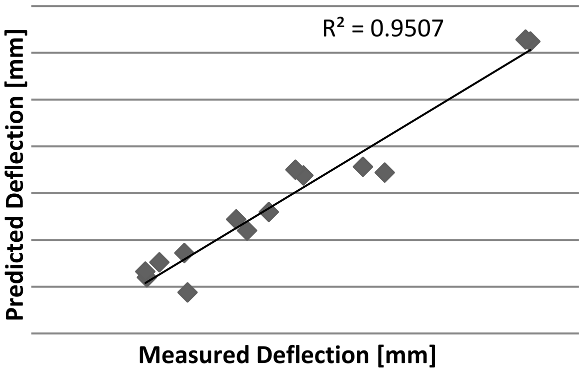

Figure 5. Comparison between theoretical model and actual results – 8 kN/m loading.

Table 3 summarises the R^2 values for Figures 3-5. It can be observed that the smaller the load is, the less accurate the model is. The bigger the load gets, the more accurate the model becomes.

Table 3. R^2 Values.

Applied Load (kN/m)	R^2 Value
4	0.9227 – 92.27 %
8	0.9507 – 95.07 %
12	0.977 – 97.70 %

This happens because small loads correspond to low stresses and low deflections. It is indeed more difficult to accurately estimate those very small numbers. For the purpose of this model, this is not particularly concerning.

As already stated, small loads correspond to low deflections and low stresses, hence, even if the error is big in proportion, it is still small in absolute terms. As a consequence, this error doesn't pose any risk to a design, especially given the fact that it is possible to address the eventual underestimation using partial safety factors.

In order to make the design even more accurate, variable safety factors have been introduced so that to low loads will correspond to higher safety factors.

5 CONCLUSIONS

The performance of a masonry support system depends on many factors, directly or indirectly. Bracket thickness, angle thickness, shimming, lock washer thickness, fixing point, and bracket centres are all parameters which define a particular system. The geometry itself is fundamental.

Two systems with different material thickness and different geometry can indeed carry the same load because all the structural parameters act as a whole in defining the system performance.

Exploiting the design model and the testing procedure described in this paper, it's been possible to increase system efficiency whilst reducing the amount of steel. The IG predictive model has a proven accuracy of more than 97% at design load.

ACKNOWLEDGEMENTS

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