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SHEFFIELD HALLAM UNIVERSITY

DEPARTMENT OF ENGINEERING AND MATHEMATICS

TESTS TO DETERMINE THE REACTION TO SOFT BODY IMPACTS OF A FREE STANDING TOUGHENED GLASS SQUASH COURT BACKWALL WITH FULL HEIGHT DOOR

FOR

PROSPEC LTD OF CANKLOW INDUSTRIAL ESTATE,

WEST BAWTRY ROAD, ROTHERHAM S60 2XL, UK

CONDUCTED IN 1981 BY GRAHAM COCKERHAM BEng, MPhil, CEng, MIMechE

PROFESSOR OF ENGINEERING DESIGN

REPORT RE-WRITTEN JANUARY 2013

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TESTS TO DETERMINE THE REACTION TO SOFT BODY IMPACTS OF A FREE STANDING TOUGHENED GLASS SQUASH COURT BACKWALL WITH FULL HEIGHT DOOR

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Tests carried out by;

GCockerham

RM Wilkinson (Principal Technician)

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1. INTRODUCTION

This report describes the results of tests carried out to determine the reaction of a toughened glass squash court backwall to impact loads representing the collision between players and the wall.

The tests were carried out at the former premises of the company at Orgreave Drive in Sheffield in 1981, using equipment and procedures based upon those contained in American National Standard ANSI Z97.1 - *Safety Glazing Materials Used in Buildings - Safety Performance Specifications and Methods of Test.* The original standard was dated 1975, but has been updated regularly to the current version which was released in 2009, although the parts of the standard used in 1975 are still valid today. Some enhancements to the original standard were used, based on the higher levels of impact energy likely to occur in squash court play.

2. BACKGROUND

2.1 The Company

The original Ellis Pearson glass backwall was designed and installed on a squash court in Sheffield in 1971. Over the years many more were installed and following the rapid expansion of squash and racquetball, consideration was given to the development of a scientific method for demonstrating the strength and safety of installations made from tempered glass and their associated fixing components. It was felt that a physical testing programme was necessary due to the complex nature of the structure and the conflicting theoretical and computer methods available at that time. It is felt that this is still the case at the present time. Since the original test programme the company has installed many hundreds of glasswall products and derivatives without any significant issues.

2.2 Sheffield City Polytechnic/Sheffield Hallam University

At the time of the original tests, an approach was made to the local Polytechnic (since converted to Sheffield Hallam University) and then Senior Lecturer Graham Cockerham was engaged to advise on and deliver the test programme. Since the completion of the test programme he has continued to provide consultancy support to the company and is currently Professor of Engineering Design within the Department of Engineering and Mathematics at the University.

a PVC sack which was taped and firmly packed into the canvas bag, which was again taped to produce a solid coherent mass. In keeping with the recommendations of Z97, the bag was suspended from a 7 ft wire rope and fastened to an overhead beam so as to position the bag, when at rest, with its maximum diameter no more than 12mm(1/2 inch) from the test wall. In addition, the bag was draped with a soft cloth prior to each impact. The actual mass of the bag when weighed was 104 kg and the pendulum drop height to achieve the desired test impact energy was calculated from the formula for the release of potential energy ie Mgh where M = 104 kg, g =gravitational acceleration = 9.81 m/s^2 and h = drop height. This resulted in a drop height of 575 mm (22.7 in) to produce the test energy of 580 Nm.

4. TEST SAMPLE AND PROGRAMME

4.1 Test Sample

The sample under test was a standard two panel, freestanding Ellis Pearson squash court glass backwall with a full height door to 2134 mm (7 ft) and two side hinges. Steel frame towers were used to support the backwall and simulate the restraint and location normally provided by squash court sidewalls; the glass fins were bolted to a concrete base as per normal installations. All fixtures and fittings were identical to those used in formal installations; the test arrangement is shown in figure 1.

4.2 Test Programme

The primary objective of the test programme was to verify the structural integrity of the backwall under the impact energy defined in section 3. Impacts were applied at a height of 1.47 m above floor level representing a typical player shoulder height. Three impact positions were used as follows;

a. Centrally on the main panel
b. centrally on the door
c. directly behind the large fin adjacent to the door space.

All impacts were applied from the play side of the wall, approaching the final value progressively by using 25%, 50%, 75% and 100% of 580 Nm at each location. in addition, the wall was instrumented with strain gauges and displacement transducers to provide further detailed data on the wall's performance. Of particular interest was the relative deflection between the wall and the door edge, in order to establish the gap and avoid the danger of 'finger trapping' which might occur in play.

5. INSTRUMENTATION

5.1 Strain Measurements

Measurements were taken from wire resistance strain gauges bonded in position at least 24 hours prior to the tests, and covered in polyurethane spray. Dummy gauges were used to compensate for temperature variation and incorporated into a 4 gauge bridge circuit. The active gauges were positioned as follows;

a. centrally on the main panel in a vertical and horizontal orientation
b. centrally on the door in a vertical and horizontal orientation
c. on the top of the hinge web for both hinges
d. adjacent to the edge fin on the main panel in a vertical and horizontal orientation

These positions were considered to be the most vulnerable locations.

5.2 Displacement Measurements

These were taken using LVDT transducers mounted on a frame secured solidly to the concrete base. The transducers were located as follows;

a. horizontally on main panel, midway between hinges, close to the door joint
b. horizontally on door, midway between hinges, close to the door joint
c. horizontally on hinge fin, midway between hinges, close to the door joint

6. RESULTS

Selected results are shown in table 1.
The most obvious and important information is that all tests were completed without breakage.
The stresses in the door at maximum impact were well below glass failure stress at 14 N/mm^2 horizontally and 33 N/mm^2 vertically (2052 and 4840 lb/in^2 respectively). Even better results were obtained for the main panel with 20 N/mm^2 and 14 N/mm^2 respectively (2900 and 2052 ib/in^2). These suggest that the wall and door are well within safe operating conditions for the impact used.
Significant movement of the wall and door occurred during the tests impacting the door and the hinge fin. For the former test, a graph is shown at figure 2 of finger trap gap against impact energy, showing a value of 13mm(0.52 in) at 580 Nm. Since the tests were completed, the WSF has incorporated a fingertrap limit of 12mm for a test impact energy of 530 Nm with which the reported test results conform.

Table 1 - Results for impacts at door, hinge fin and main panel

Table 1a - deflections due to door impact in mm

% impact	Fin	Frame	Door	Difference	gap
25% initial	5	15	26	11	-1
25% residual	0	2	0		
50% initial	8.5	16	30	14	2
50% residual	0	0	0		
75% initial	10	21	40	19	7
75% residual	0	3	0	0	
100% initial	13.5	24	49	25	13
100% residual	0	0	0	0	

Table 1b-stresses due to door impact

% impact	Vertical stress in door (N/mm^2)	Horizontal stress in door (N/mm^2)
25%	12.7	5.9
50%	24.1	9.5
75%	28.2	11.2
100%	32.8	14.0

Table 1c - deflection in mm due to fin impact

% impact	fin	frame	door	difference	gap
25%	6	12	28	16	4
50%	6	20	38	18	6
75%	11	29	51	22	10
100%	13	39	60	21	9

Table 1d - Stresses due to panel impact in N/mm^2

% impact	Panel centre horizontal	Panel centre vertical	Fin horizontal	Fin vertical
25%	10.8	8.5	1.2	4.6
50%	12.4	10.1	1.4	5.3
75%	16.8	11.2	1.6	6.8
100%	19.6	13.6	2.4	8.0

Table 1e - Deflection in frame due to panel impact

% impact	Frame deflection (mm)
25%	2
50%	3
75%	4.5
100%	6

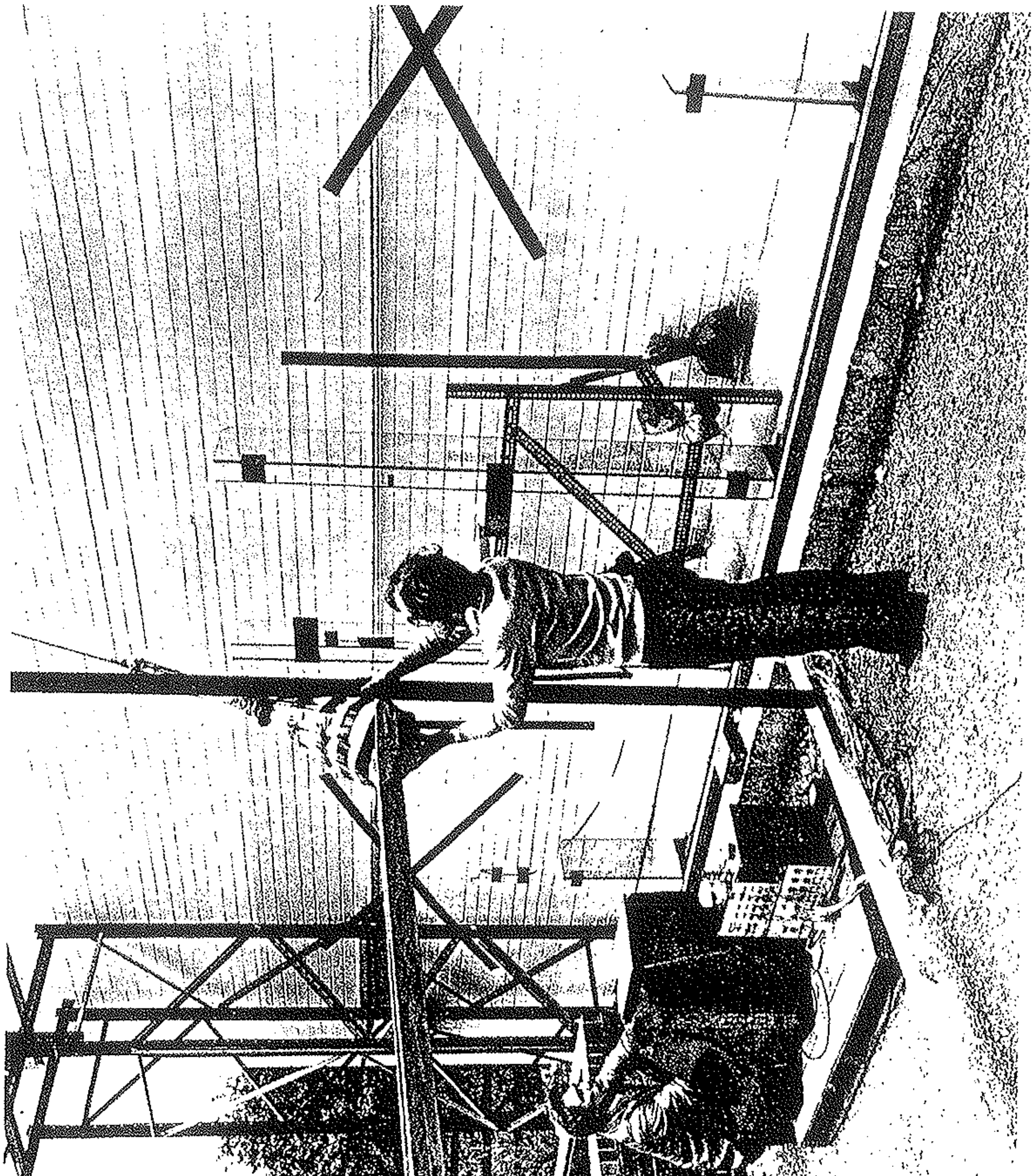

Figure 1 Test Arrangement and Method of Impact Application

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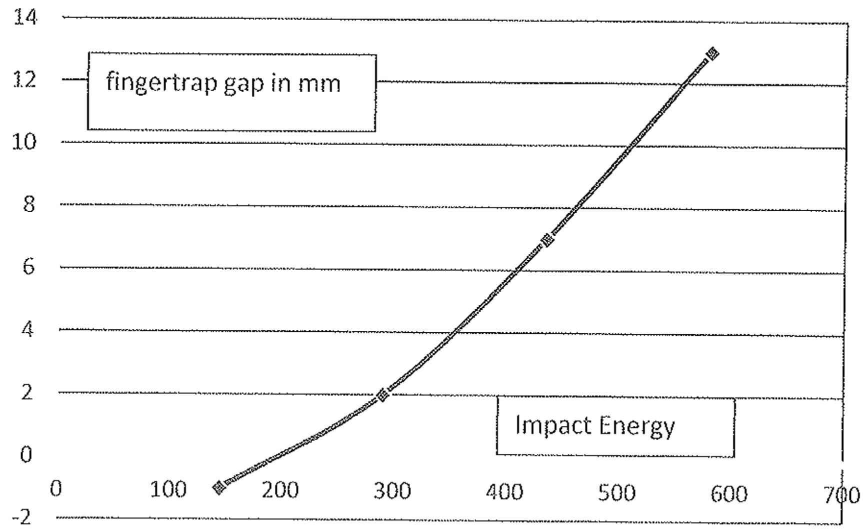
Figure 2 Fingertrap Gap as a function of Impact Energy



3. THE TEST

3.1 Standards

At the commencement of the investigations in 1979 there was no specific standard dealing with use of safety glazing in squash or racquetball courts. However the American National Standards Institute, Z97 standard was available in 1975 making recommendations on the use o safety glazing in buildings. At that time, this standard had been adopted or recommended by other national organisations included the British Standards Institute and German DIN. ANSI Z97 proposed a typical impact from a 45kg mass impacting at a speed of 6.6m/s resulting in a kinetic energy of $0.5Mv^2 = 0.5 \times 45 \times 6.6^2 = 1000$Nm. For imperial units the mass is 100lb impacting at a speed of 22 ft/s giving kinetic energy of 755 ft lb. The Z97 standard recognises that this impact energy can come from different combinations of mass and speed and for squash and raquetball applications. It was felt that a kinetic energy value of 1000 Nm achieved through a mass of 100kg(224 lb) and a speed of 4.5m/s(15 ft/s) would be typical of game impacts, although tests were conducted at a 10% higher kinetic energy level of 1100 Nm. ANSI Z97 has been revised on several occasions since the original tests were conducted, with the latest version being issued in 2009; the above impact levels have been retained within the current version of the standard.

3.2 Test Procedure

3.2.1 Test Impact Energy

As mentioned above a game kinetic energy of 1100 Nm was judged to be suitable for squash and raquetball applications, however not all of this is transferred to the structure, with a test energy being determined using a transfer factor of 0.53 as recommended by ANSI Z97. This is due to energy absorption by the impacting body and results in a requirement for a test impact of 0.53 x 1000 = 530Nm, which again was increased to 580Nm (440 ft lb). At the time of completing the tests in 1989, the International Squash Raquets Federation was in the process of developing a testing standard based on ANSI Z97, which is now incorporated into the World Squash Federation standards with the same impact energy.

3.2.2 Method of Impact

The method of impact recommended in Z97 is to use a punch bag filled with 45kg of lead shot suspended from a wire rope of minimum length 1.5m (5 ft) and swung into the test wall in a pendulum fashion. For this particular test, it was necessary to use a stout canvas bag to accommodate the 100kg mass. Lead shot was tightly packed into

FURTHER TESTS TO DETERMINE THE REACTION TO SOFT BODY IMPACTS OF A

TWO PANEL TOUGHENED GLASS SQUASH COURT BACKWALL

WITH SUPPORTING POSTS

FOR

PROSPEC LTD OF CANKLOW INDUSTRIAL ESTATE,

WEST BAWTRY ROAD, ROTHERHAM S60 2XL, UK

CONDUCTED IN 1981 BY GRAHAM COCKERHAM BEng, MPhil, CEng, MIMechE

PROFESSOR OF ENGINEERING DESIGN

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This test was conducted on a two panel, 'Club' type wall 21ft wide by 7ft high (6400mm by 2134mm) with full height door and side hinges, using the equipment and methods described above. Each panel was supported by one standard vertical aluminium post connected to a top beam of structural steel having a second moment of area of 6 x 10^6 mm^4aout an axis parallel to the plane of the glass. Each post was secured to a concrete base and all fixtures and fittings were the same as for a normal installation. The wall was supported at the edges by steel towers to simulate the restraints and location provided by court side walls.

IMPACT TESTS

Tests were carried out in accordance with the procedures described above with impacts at the centre of the door, centre of the panel and edge of the panel, 350mm from the hinge door joint. All impacts were applied at a height of 1.47m. Impacts were applied progressively for 25%, 50%, 75% and 100% of the total impact energy of 580Nm and deflections were measured at a vertically central point of 1.05m above ground level as shown in Table 2. For an impact energy of 580Nm, there were no fingertrap gaps, which obviously complies with the WSF recommendations of 12mm maximum. Stress measurements were not taken, but no breakages occurred for any applied impact energy.

Table 2 - Results for Door and Panel Impact - deflections in mm

Table 2a - Deflections due to central door impact in mm

% impact	Panel centre	frame	door	difference	gap
25%	9	12	14	2	-10
50%	14	16	18	2	-10
75%	20	22	23	1	-11
100%	24	26	27	1	-11

Table 2b - Deflections due to central panel impact in mm

% impact	Panel centre	frame	door	difference	gap
25%	22	11	7	4	-8
50%	27	17	10.5	6.5	-5.5
75%	30	20	12	8	-4
100%	32	25	13	12	0

Table 2c - Deflections due to panel edge impact in mm

% impact	Panel centre	frame	door	difference	gap
25%	10	14	16	2	-10
50%	14	18	20	2	-10
75%	17	21	24	3	-9
100%	20	25	28	3	-9

FURTHER TESTS TO DETERMINE THE REACTION TO SOFT BODY IMPACTS OF A

FREE STANDING FOUR PANEL TOUGHENED GLASS SQUASH COURT

BACKWALL

FOR

PROSPEC LTD OF CANKLOW INDUSTRIAL ESTATE,

WEST BAWTRY ROAD, ROTHERHAM S60 2XL, UK

CONDUCTED IN 1981 BY GRAHAM COCKERHAM BEng, MPhil, CEng, MIMechE

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This test was conducted on a four panel, freestanding raquetball backwall, 6100mm wide x 3600mm high (20ft x 12ft) with a central door, 2134mm high (7ft) door and side hinges, using the equipment and methods described above. The wall was secured by normal glass fins to a concrete base and all other fixtures and fittings were the same as for a normal installation. The wall was supported at the edges by steel towers to simulate the restraints and location provided by court side walls

IMPACT TESTS

The wall was tested by means of impacts to the centre of the door and the edge of the panel adjacent to the door at a height of 1.5m (5ft) above ground level. Impacts were applied progressively at 25%, 50%, 75% and 100% of the 580Nm adopted for the test programme. Deflection measurements were taken and are shown in Table 3, with a maximum fingertrap gap of 5mm observed for a full central door impact, which complies with WSF recommendations of 12mm maximum. No breakages occurred and no stress measurements were taken.

Table 3 - Results for Door and Edge of Panel Impact - deflections in mm

Table 3a - Deflections due to central door impact in mm

% impact	Panel centre	frame	door	difference	gap
25%	4	6	14	8	-4
50%	12	15	24	9	-3
75%	26	21	33	12	0
100%	30	24	41	17	5

Table 3b - Deflections due to edge panel impact in mm

% impact	Panel centre	frame	door	difference	gap
25%					
50%	18	10	14.5	4.5	-7.5
75%	22	14.5	21.5	7	-5
100%	26	17.5	29	11.5	-0.5