CPRC

CANADIAN POLICE RESEARCH CENTRE

CCRP

CENTRE CANADIEN DE RECHERCHES POLICIERES

TM-09-95
IMPACT LOADING TESTS FOR UPGRADING THE SECURITY OF EXISTING WINDOWS

By: G. Pernica, D.A. Taylor, F. Rajan and R. Glazer
Institute for Research in Construction
National Research Council of Canada

TECHNICAL MEMORANDUM

Submitted by
Institute for Research in Construction
National Research Council of Canada

April, 1995

NOTE: Further information about this report can be obtained by calling the CPRC information number (613) 998-6343

SUMMARY

This is an interim report on a project that evaluated the resistance of windows to forced entry by an unskilled attacker using a sledge hammer. To ensure the safety of the attacker and to keep the cost of instrumentation to a minimum, high strength aluminum plates of the same modulus and density as glass were used instead of glass. Aluminum responds like glass under impact, but does not break.

The information collected will be used to design a “standard” test procedure and to build special test equipment for evaluating “window” systems proposed to replace single- or double-glazed windows where enhanced security is required.

RESUMÉ

Ce rapport provisoire porte sur un projet ayant permis d'évaluer la resistance des fenetres aux entrees par infraction par un amateur utilisant une masse. Pour assurer la sécurité de l’amateur et limiter autant que possible les coûts de materiel, on a utilisé au lieu de fenetres en verre des feuilles d’aluminium à haute resistance de la même densité et du même module que le verre. L’aluminium réagit comme le verre sur impact, mais il ne casse pas.

L’information recueillie servira 8 élaborer une procedure de test <standard> et à concevoir de l’equipement d’essai special permettant d'évaluer les systèmes de fenetres proposes pour remplacer les fenetres à simple ou à double vitrage aux endroits où la sécureté doit être accrue.

IMPACT LOADING TESTS FOR UPGRADING THE SECURITY OF EXISTING WINDOWS

G. Pernica†, D.A. Taylor?, F. Rajan‡ and R. Glazer?

†Institute for Research in Construction, National Research Council of Canada
Montreal Road, Ottawa, Ontario, K1A OR6

‡Co-op Student, Simon Fraser University
Burnaby, British Columbia, V5A 1S6

ABSTRACT

The paper describes a project aimed at evaluating the resistance of windows to forced entry by a unskilled attacker using a sledge hammer. Manual force attacks by a vigorous 90 kg man using a 5.4 kg sledge hammer outfitted with a force transducer were made against three sizes of windows held vertically in a special test frame. To ensure the safety of the attacker and to keep the cost of instrumentation (strain gauge rosettes, in particular) to a minimum, high strength aluminum plates, 6 mm thick were used instead of 6 mm glass. Because aluminum has the same Young's modulus and density as glass, it responds like glass under impact, but without breaking.

Aluminum window frames were instrumented with accelerometers, force transducers and a laser diode and the windows with strain gauges. The gauges were positioned to identify impact locations which gave the highest strains. The gauges also helped to determine whether smaller and, therefore, less expensive windows than those tested could be used to simulate the dynamic behaviour of large windows (1500 x 1800 mm and larger). The laser diode was placed in front of the window frame and used as a triggering device to obtain the speed and, therefore, the kinetic energy of the hammer just prior to impact. The information collected from the impacts will be used to design a 'standard' test procedure and to build special test equipment for evaluating 'window' systems proposed to replace single- or double-glazed windows where enhanced security is required.

INTRODUCTION

For many buildings there is a need to upgrade the resistance of existing windows to resist attempts at break-and-enter or smash-and-grab. There are many ways to upgrade the security of windows exposed to unlawful actions. Some incorporate the application of plastic films to the existing glass, while others require removal of the glass and replacement with a much tougher, though transparent, window system. Although a number of national standards exist for evaluating the resistance of windows to human body impact and to assault by skilled and unskilled attackers during break-and-enter attempts, there is no detailed technical data published as background to these standards (AS 2208 1978, ASTM F1233 1992, BS 6206 1981, BS 5544 1978, CAN/CSA-A440 M90 1990, DIN 52 338 1985, DIN 52 337 1985, UL 972 1984). Indeed, there are substantial discrepancies in the impact energies required from standard to standard.

At the request of the RCMP, the Institute for Research in Construction of the National Research Council of Canada (IRC/NRCC) undertook a project to determine experimentally, the impact forces and the dynamic responses induced by a vigorous 90 kg man using a 5.4 kg sledge hammer against three sizes of window. The objective was to use the data obtained from these attacks to design a test protocol for evaluating the security of existing commercial window systems against an unskilled attacker.

DESIGN OF EXPERIMENTS

Test Setup

To make the experiments realistic, a test frame was constructed from steel members (hollow structural sections and angles) to hold the windows vertically in commercial aluminum window frames with the mid-height of the windows at the shoulder height of the 90 kg ‘attacker’ (1525 mm above the laboratory floor). The steel frame was rigidly constructed and supported on a concrete floor slab to minimize its dynamic response to sledge hammer impacts. The commercial window frames, nominally 1525 x 1830 mm (5 x 6 ft.), 915 x 1220 mm (3 x 4 ft.) and 915 x 760 mm (3 x 2 1/2 ft.), were made to hold double-glazed windows consisting of two panes of 6 mm glass separated by a 12 mm air space. For the impact tests, however, a single 6 mm pane was installed in the frames with a standard aluminum spacer (commercially-manufactured filler made for this purpose) to take up the unused thickness. Ordinary glazing gaskets supplied with the window frames (dry glazing for the outside surface and wet for the inside surface of the window) were used to install the 6 mm panes.

To ensure the safety of the attackers and to considerably lessen the costs of glass, instrumentation and labour, 6 mm thick high strength aluminum plates (7075-T651) were used instead of 6 mm glass. Because aluminum has about the same Young’s modulus and density as glass, it responds like glass under impact loading, but without breaking. Indeed, the aluminum ‘panes’ survived all impacts sustaining only superficial surface damage.

Although the primary interest was of windows of the size used in commercial establishments, three sizes were tested, each using a 6 mm aluminum plate as the ‘glass’ to determine whether size was an important parameter. The hope was that small windows would behave dynamically the same as larger ones, thereby saving money in the future testing program which would evaluate the security of existing windows. The clear spans of the window panes tested were 890 x 735 mm, 890 x 1195 mm and 1500 x 1795 mm. The first figure for each window is its horizontal dimension as mounted in the steel frame. The largest window was struck by the sledge hammer at four locations (R, S, T, and U) in the lower left-hand quadrant of the pane (Fig. 1) and the two smaller windows at three of these four locations (R, S, and U).

<u>Instrumentation</u>

The sledge-hammer was made by cutting the ends off a standard 3.6 kg (8 lb.) sledge and putting it back together with a 360 kN force transducer inserted just behind the striking head and a 150 mm long spacer (threaded steel rod and plastic tube) placed in front of the other head to counterbalance the weight of the force transducer assembly. The piezoelectric transducer had a sensitivity of 0.014 mv/N from about 2 Hz to 1500 Hz. In addition, each corner of the aluminum frame was attached to the steel frame by way of a 110 kN piezoelectric force transducer (sensitivity of 0.045 mv/N from about 2 Hz to 3500 Hz) which measured the dynamic forces sustained by the window frames and transferred to the steel frame during and following the impact.

The aluminum ‘panes’ were instrumented with seven sets of strain gauges on their back surfaces. The gauges were installed behind two of the impact locations (Locations S and U) and five other positions within the lower-left quadrant struck by the hammer (Fig. 1). Strain rosettes were applied at two gauge positions (behind Location U and near the corner of the pane), biaxial gauges at three positions (behind Location S and at the quarter points of the pane’s two principal axes) and uniaxial gauges at the remaining two positions (near the edges of the pane’s two axes). The gauges were placed to find the locations most stressed during each impact. Gauge positions were selected directly under two impact locations to see if the induced dynamic stresses were highly localized (assuming the attacker could accurately strike selected target points).

A laser diode was placed across the trajectory of the sledge hammer about 150 mm in front of the surface of the window. By measuring the time of travel between the hammer breaking the light beam and striking the plate, the average velocity of the hammer over its final 150 mm of travel prior to impact was determined.

Signals from force transducers, strain gauges and the laser diode were linked to a computer-based, multi-channel, data acquisition system. The signals were amplified, low-pass filtered at 1000 Hz, digitized at 3000 Hz and stored on computer disk. A commercial software package controlled the A/D board, displayed the digitized signals and analysed those portions of the signals containing impact-induced responses.

Test Method

To obtain a better understanding of window behaviour under impact, many hits were made and recorded at low-level forces before the 90 kg attacker struck the windows with as much gusto as possible. The lower force levels, 2 kN, 5 kN and 10 kN, were applied to each impact location on the windows by assailants who controlled the swing of the hammer by ‘bunting’ as in baseball with hands separated. A minimum of two repetitions of each force level were applied depending on the accuracy and force repeatability of the assailant. The fourth and highest level of impact was applied by the 90 kg attacker using maximum effort. To deliver impacts with forces which ranged from 18 kN to 25 kN, the assailant kept his hands together, forming a pivot point as the hammer contacted the window.

Transducer signals were recorded and displayed for each impact conducted on the windows. The same series of tests was repeated for each window size except that impact Location T was struck only on the largest window. In addition, for the hardest hits, the distance between the actual point of impact on the aluminum plate and the intended target location (Location S, for example) was measured. These hit locations were easy to identify because the surface of the aluminum panes was slightly scored by each impact.

TEST RESULTS

Contact Time and Velocity

Time histories of sensor signals (force transducers, strain gauges and laser diode) recorded for each impact were displayed and plotted using the commercial software. Contact time, i.e. the amount of time the sledge hammer was in contact with the aluminum ‘pane’, was determined for each impact from the time history of the force transducer inserted into the sledge hammer (Fig. 2). An important trend observed for all three sizes of windows was: the higher the hammer force, the lower the contact time (Fig. 3). This relationship suggested that for the hardest hits, the body weight of the 90 kg attacker contributed little to the mass of the impactor.

Observations indicated that the attacker’s body lifted and accelerated the hammer towards the window, becoming a pivot point as his hands slid together on the handle just prior to impact. At this point the attacker was intuitively trying not to crush his hands between the handle and the window and not to fall into the window (to be bruised by the aluminum pane or badly cut if it were glass). Many photographs taken during these high impact blows illustrate this point. Consequently, it can be assumed that the energy delivered to the window during the impact is almost entirely due to the mass of the sledge-hammer head travelling at the measured velocity (Fig. 4). Velocities for the hardest hits varied between 10 m/s and 15 m/s. This information helped derive a height from which to drop a weight to give the required kinetic energy at impact.

Window Strains

To determine where the maximum strains occurred during each impact, strains obtained from the seven gauge locations for each 10 kN impact were plotted and compared. The plots clearly indicated that the maximum strains for each impact occurred directly under the impact location. Graphs of maximum strains, that is strains obtained at Locations S and U for impacts at Locations S and U respectively, were plotted for each impact for the three window sizes. Figures 5 and 6 show the maximum strains, measured at Locations S and U, for the largest and smallest windows. Strains were placed on the force axis by the software program when either the strain gauge failed during the testing program or the gauge signal overloaded the digital recording system.

Comparison of maximum strains indicated that strains at Location U were on average about 50% higher than those at Location S for impacts above 18 kN but that for these same impacts there were no significant differences between the three window sizes in the strains at either location. This implied that small windows could be tested instead of full-sized windows, thereby saving considerable money in the extensive testing program which was to follow. Indeed, the decision was made to test the same size window (610 x 610 mm panes with clear spans of 560 mm) as specified in the American standard UL 972 (1984) and in the British standard BSI 5544 (1978).

The final issue to be resolved was whether it would be more appropriate to impact the centre (Location S) or quarter point (Location U) of the 560 x 560 mm window. Because this size window is somewhat smaller than the smallest window tested (890 x 735 mm) and square rather than rectangular, an additional piece of information obtained in the testing program was examined. As noted before, the inaccuracy of each impact struck by the 90 kg attacker was measured. The measurements indicated that these hits fell within a circle having a radius of 40 mm about the intended strike location. With this variability, the centre of the 560 x 560 mm window would be the preferred impact location as deviations from this location would produce smaller variations in stress than a location nearer the sides and corner of the window. However, as noted previously, strains at Location U were about 50% higher than those at Location S, probably because of edge restraint. Since the impact location could be controlled in a standardized test, the quarter point and not the centre point of the 560 x 560 mm window was recommended as the point of impact in the test procedure.

Standard Test Procedure

A test procedure in which an elongated 11 kg mass is dropped 5 m down a long tube to impact the quarter point of a 560 mm square window was considered a good simulation of the impact force applied to a large window by a vigorous 90 kg attacker wielding a 5.4 kg sledge-hammer during an unskilled break-and-enter attempt. Final tests on a 560 x 560 mm aluminum window, to verify the procedure, are in progress.

CONCLUSIONS

1. Maximum strains on the three aluminum windows were obtained at impact locations.

2. Window size did not have a significant effect on the measured maximum strains. A 610 x 610 mm pane (the same as used in UL 972 and BS 5544) was chosen, therefore, for the ‘standard test procedure to evaluate window security.

3. Hammer impacts delivered to the quarter points of the windows resulted in the highest strains measured in the panes. The quarter point of the 560 x 560 mm pane was recommended, therefore, as the target point of the falling weight in the ‘standard’ test procedure.

4. At full-strength hits, the hands of the 90 kg attacker became a pivot point for his body at the instant of impact. His body, therefore, did not contribute to the energy of the impact as the hammer struck the window. The mass of the hammer travelling at the measured velocity supplied all the energy to the impact.

5. The measured average velocity of the 5.4 kg hammer just prior to contact for full-strength attacks was between 10 m/s and 15 m/s. A velocity of 14 m/s was chosen for the hammer to determine the amount of energy required by the impactor in the ‘standard’ test procedure.

6. A test procedure which simulates the force applied to a large window by an unskilled attacker has been proposed. Tests to verify this procedure are in progress.

ACKNOWLEDGEMENTS

The authors acknowledge the financial assistance provided by the Royal Canadian Mounted Police and the Canadian Police Research Centre at the National Research Council of Canada. The authors thank the following members of the RCMP who were extremely helpful in planning and conducting the full-strength attacks on the window systems; Mr. Larry L. Blanchette, Mr. Greg Robertson, Mr. J.G. Ross Adams, Mr. Terry Thorn and Mr. Larry Clement.

REFERENCES

AS 2208, 1978. Safety Glazing Materials for Use in Buildings (Human Impact Considerations), Standards Association of Australia, 1978.

ASTM F 1233, 1993. Standard Test Method for Security Glazing Materials and Systems, American Society for Testing and Materials, Philadelphia, Pa., 1993.

BS 5544, 1978. Anti-Bandit Glazing (Glazing Resistant to Manual Attack), British Standards Institution, 1978.

BS 6206, 1981. Impact Performance Requirements for Flat Safety Glass and Safety Plastics for Use in Buildings, British Standards Institution, 1981.

CAN/CSA-A440-M90, 1990. Windows, Canadian Standards Association, Toronto, Ontario, 1990.

DIN 52 337, 1985. Methods of Testing Flat Glass for Use in Buildings, Pendulum Impact Tests, Deutsches Institut für Normung, Berlin, Germany, 1985.

DIN 52 338, 1985. Methods of Testing Flat Glass for Use in Buildings, Ball Drop Test on Laminated Glass, Deutsches Institut für Normung, Berlin, Germany, 1985.

UL 972, 1984. Burglary Resisting Glazing Material, Underwriters Laboratories Inc., Northbrook, Illinois, 1984.

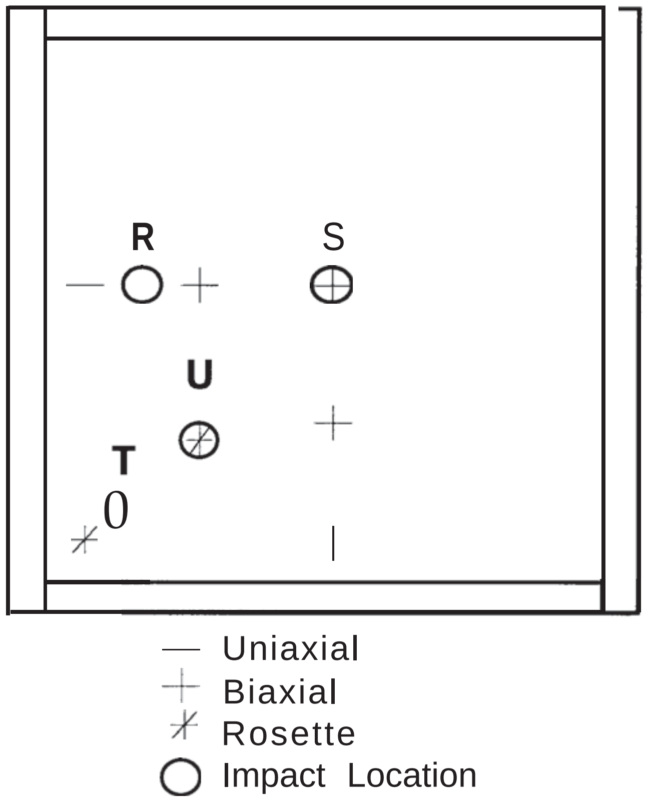

Figure 1 Layout of Impact Locations and Strain Gauges on the Three Windows

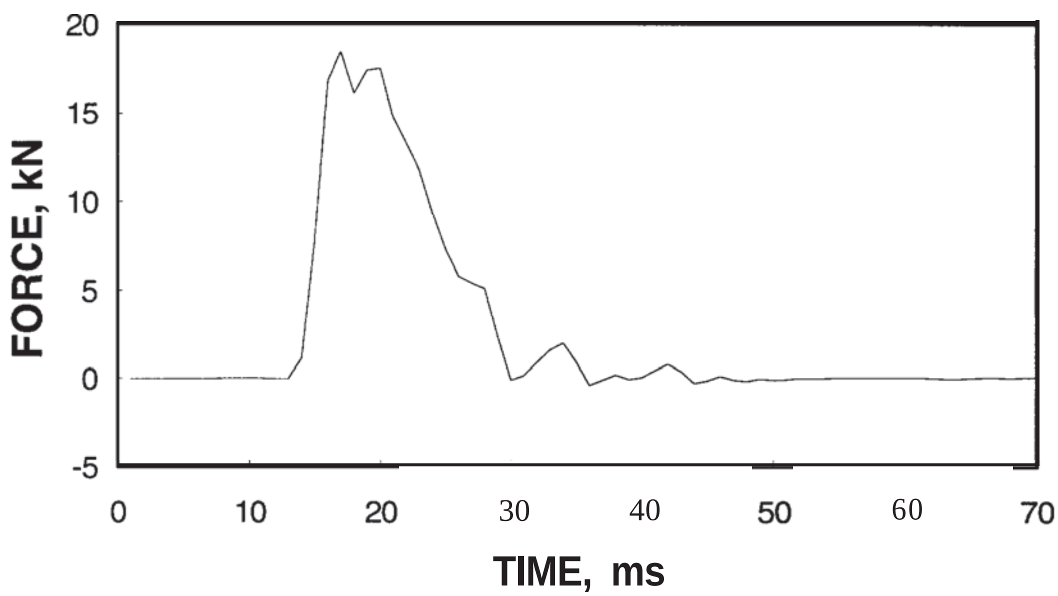

Figure 2 Force Time History Produced by the 90 kg Attacker Striking Location S on the Large Window

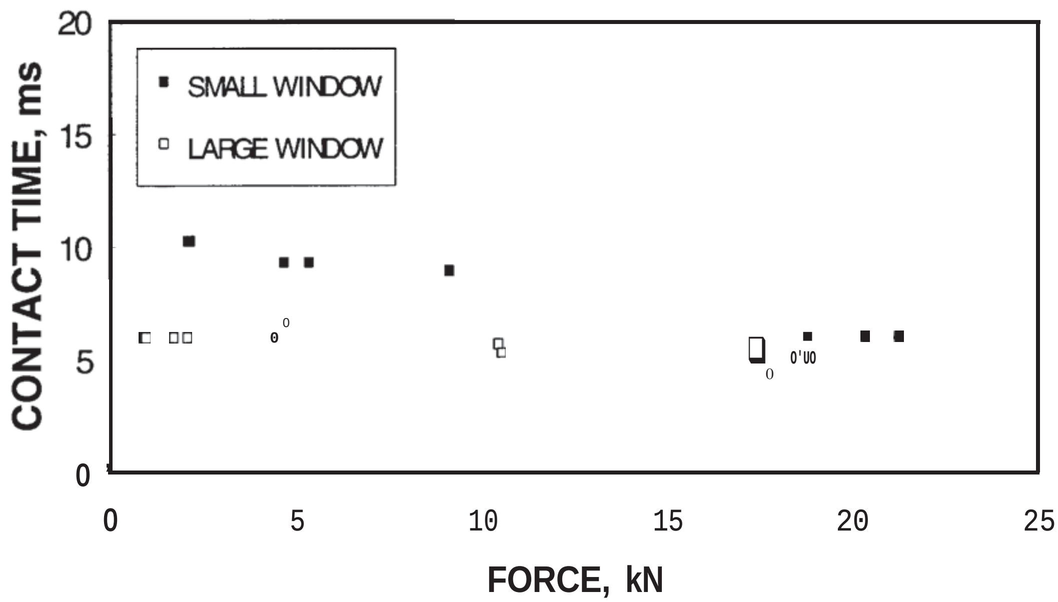

Figure 3 Contact Time of the Sledge Hammer for Impacts on the Small and Large Windows at Location U

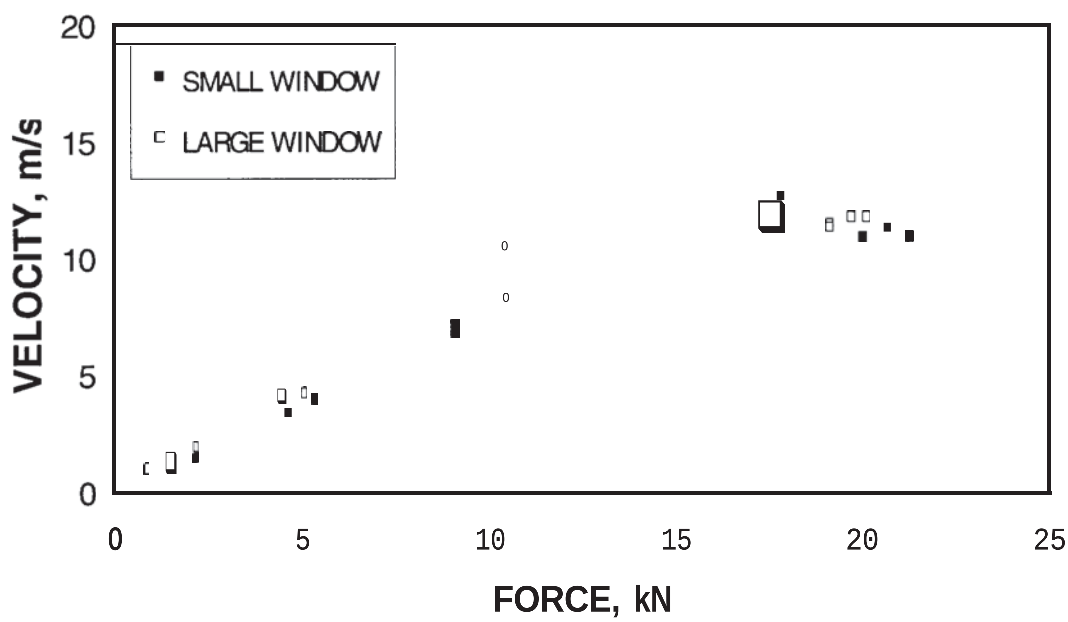

Figure 4 Velocity of the Sledge Hammer for Impacts on the Small and Large Windows at Location U

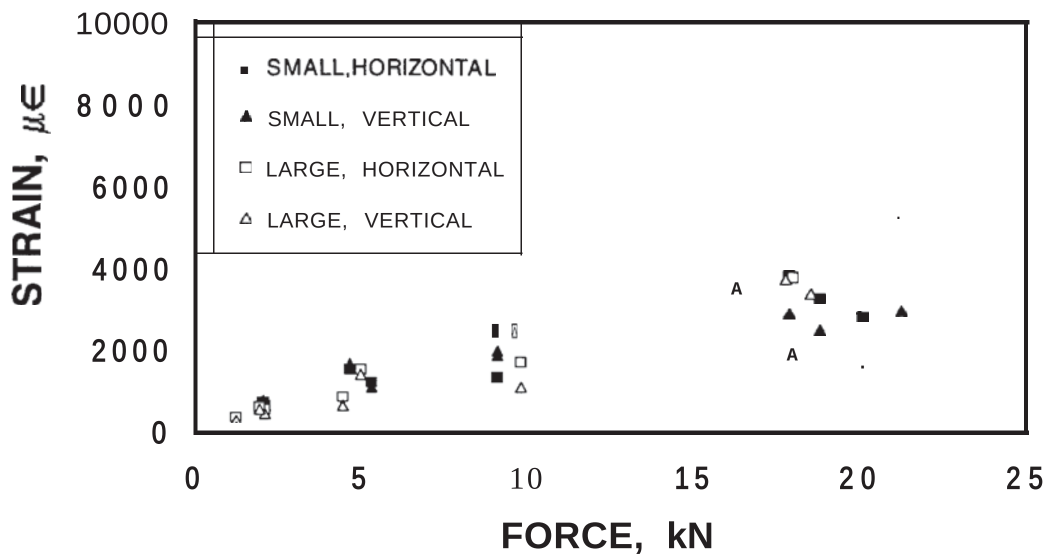

Figure 5 Maximum Horizontal and Vertical Strains in the Small and Large Windows for Hammer Impacts at Location S

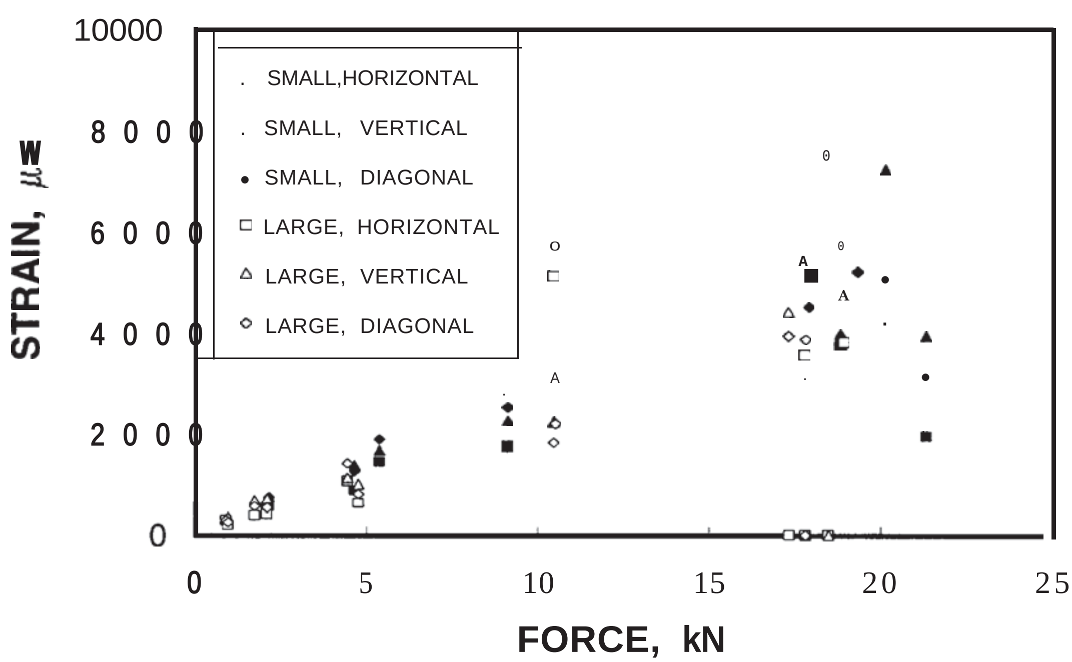

Figure 6 Maximum Horizontal, Vertical and Diagonal Strains in the Small and Large Windows for Hammer Impacts at Location U