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Test Method for the Evaluation of the Penetration Resistance of High-Security Glazing Subjected to a Combined Attack of Heat and Mechanical Impact

NIJ Report 301–85

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ACKNOWLEDGMENTS

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FOREWORD

The Law Enforcement Standards Laboratory (LESL) of the National Bureau of Standards (NBS) furnishes technical support to the National Institute of Justice (NIJ) program to strengthen law enforcement and criminal justice in the United States. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

LESL is: 1) Subjecting existing equipment to laboratory testing and evaluation and 2) conducting research leading to the development of several series of documents, including national voluntary equipment standards, user guides, and technical reports.

This document covers research on law enforcement equipment conducted by LESL under the sponsorship of NIJ. Additional reports as well as other documents are being issued under the LESL program in the areas of protective equipment, communications equipment, security systems, weapons, emergency equipment, investigative aids, vehicles, and clothing.

Technical comments and suggestions concerning this report are invited from all interested parties. They may be addressed to the Law Enforcement Standards Laboratory, National Bureau of Standards, Gaithersburg, MD 20899.

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COMMONLY USED SYMBOLS AND ABBREVIATIONS

A	ampere	H	henry	nm	nanometer
ac	alternating current	h	hour	No.	number
AM	amplitude modulation	hf	high frequency	o.d.	outside diameter
cd	candela	Hz	hertz (c/s)	Ω	ohm
cm	centimeter	i.d.	inside diameter	p.	page
CP	chemically pure	in	inch	Pa	pascal
c/s	cycle per second	ir	infrared	pe	probable error
d	day	J	joule	pp.	pages
dB	decibel	L	lambert	ppm	part per million
dc	direct current	L	liter	qt	quart
°C	degree Celsius	lb	pound	rad	radian
°F	degree Fahrenheit	lbf	pound-force	rf	radio frequency
diam	diameter	lbf·in	pound-force inch	rh	relative humidity
emf	electromotive force	lm	lumen	s	second
eq	equation	ln	logarithm (natural)	SD	standard deviation
F	farad	log	logarithm (common)	sec.	section
fc	footcandle	*M*	molar	SWR	standing wave radio
fig.	figure	m	meter	uhf	ultrahigh frequency
FM	frequency modulation	min	minute	uv	ultraviolet
ft	foot	mm	millimeter	V	volt
ft/s	foot per second	mph	mile per hour	vhf	very high frequency
g	acceleration	m/s	meter per second	W	watt
g	gram	N	newton	λ	wavelength
gr	grain	N·m	newton meter	wt	weight

area = unit^2 (e.g., ft^2, in^2, etc.); volume = unit^3 (e.g., ft^3, m^3, etc.)

PREFIXES

d	deci (10^{-1})	da	deka (10)
c	centi (10^{-2})	h	hecto (10^2)
m	milli (10^{-3})	k	kilo (10^3)
μ	micro (10^{-6})	M	mega (10^6)
n	nano (10^{-9})	G	giga (10^9)
p	pico (10^{-12})	T	tera (10^{12})

COMMON CONVERSIONS
(See ASTM E380)

ft/s × 0.3048000 = m/s	lb × 0.4535924 = kg
ft × 0.3048 = m	lbf × 4.448222 = N
ft·lbf × 1.355818 = J	lbf/ft × 14.59390 = N/m
gr × 0.06479891 = g	lbf·in × 0.1129848 = N·m
in × 2.54 = cm	lbf/in^2 × 6894.757 = Pa
kWh × 3 600 000 = J	mph × 1.609344 = km/h
	qt × 0.9463529 = L

Temperature: $(T_{°F} - 32) \times 5/9 = T_{°C}$

Temperature: $(T_{°C} \times 9/5) + 32 = T_{°F}$

TEST METHOD FOR THE EVALUATION OF THE PENETRATION RESISTANCE OF HIGH-SECURITY GLAZING SUBJECTED TO A COMBINED ATTACK OF HEAT AND MECHANICAL IMPACT

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A method has been developed for the evaluation of the penetration resistance of high-security glazing subjected to a combined attack of thermal and mechanical impact. The test equipment is fully described and a detailed test method is presented.

Key words: flame; glazing; heat; high-security glazing; impact; penetration resistance; test method.

1. INTRODUCTION

Transparent high-security glazing is typically manufactured from glass or plastic or multiple layers of glass and plastic in combination. High-security glazing is used in a wide variety of commercial applications, such as bank teller windows, and correctional or penal institutions. In such applications there is always the danger of an attack to breach the glazing. The nature of the attack can range from the use of firearms to implements such as a fire axe, hammer, or objects that can be used as battering rams as well as the application of heat from burning combustibles.

This report presents a test method to evaluate the penetration resistance of high-security glazing subjected to a combined attack of heat and mechanical impact. The research leading to the development of this test method is fully described, together with test results, in a separate report by the National Institute of Justice (NIJ).[1]

In presenting this test method, it is recognized that a number of other attributes of a glazing system, including different physical parameters of the glazing and the manner in which it is installed influence the overall level of security that is obtained. For example, protection from firearms is often important. NIJ Standard-0108.01, Ballistic Resistant Protective Materials [2], may be used to determine whether a glazing will resist specific firearm attacks.

It is anticipated that future research will lead to the development of additional test methods for glazing to evaluate resistance to other types of attack. Ultimately a standard should be developed that will enable the complete evaluation of high-security glazing, together with performance requirements consistent with a range of specific threat levels for a variety of high-security applications. Such a standard would be similar to those [3,4,5] previously developed for residential and small business use for selecting door and window assemblies that resist attacks that are normally of a lower magnitude than those directed against high-security facilities.

2. TEST EQUIPMENT

The test equipment required to evaluate the penetration resistance of high-security glazing to combined heat and mechanical impact is described below.

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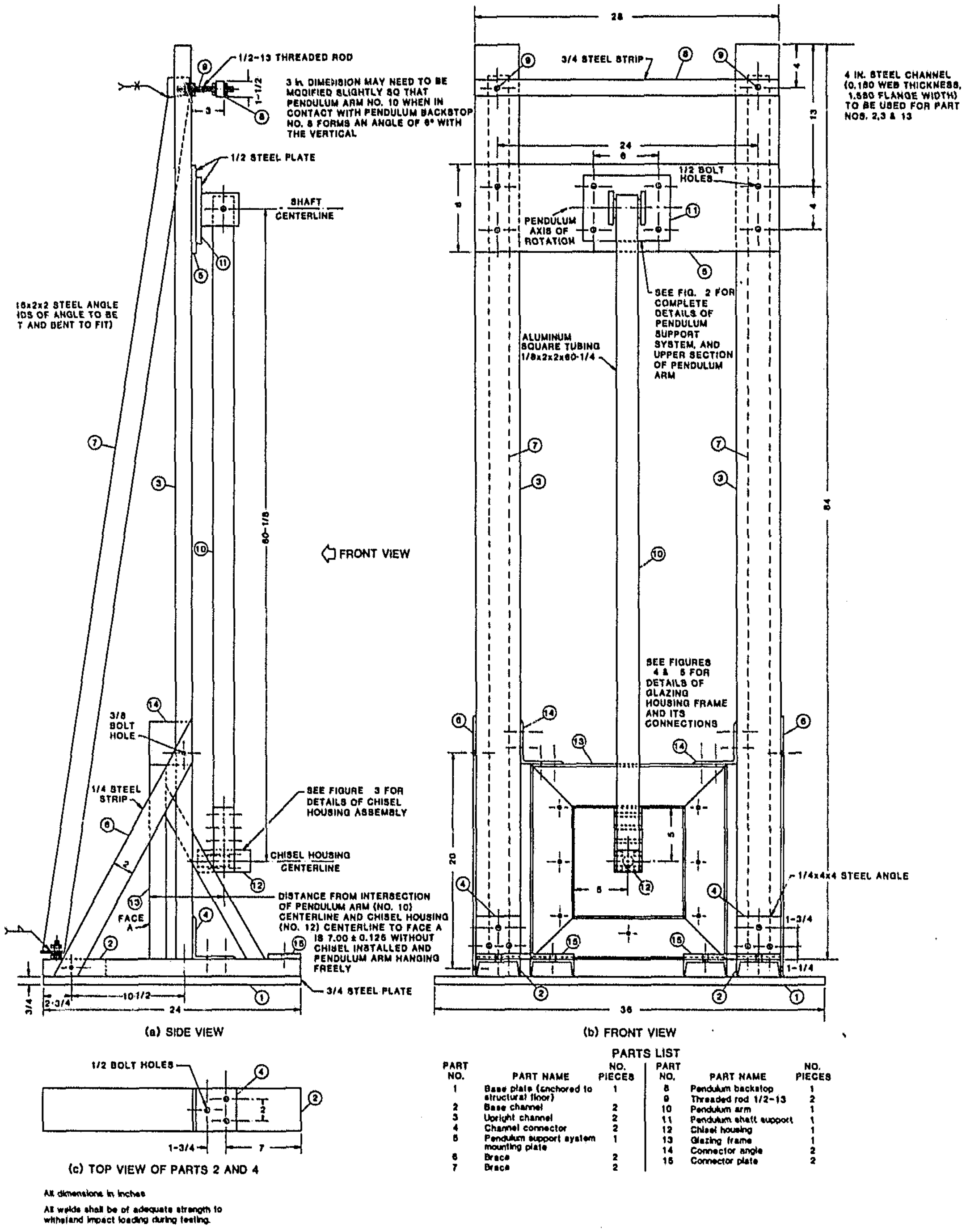
[1] Numbers in brackets refer to references in section 6.

2.1 Pendulum Impact Apparatus

A suitable pendulum impact apparatus is shown in figure 1. It consists of three basic components: a support frame constructed of rigid steel members that is securely bolted (anchored) to the concrete floor of the test facility, a free swinging pendulum arm terminated in a chisel housing assembly at the impact end, and a glazing housing assembly to hold the test specimen. The construction details of the support frame are shown in figure 1.



PARTS LIST

PART NO.	PART NAME	NO. PIECES	PART NO.	PART NAME	NO. PIECES
1	Base plate (anchored to structural floor)	1	8	Pendulum backstop	1
2	Base channel	2	9	Threaded rod 1/2-13	2
3	Upright channel	2	10	Pendulum arm	1
4	Channel connector	2	11	Pendulum shaft support	1
5	Pendulum support system mounting plate	1	12	Chisel housing	1
6	Brace	2	13	Glazing frame	1
7	Brace	2	14	Connector angle	2
			15	Connector plate	2

FIGURE 1. *Pendulum apparatus.*

The pendulum arm must be of sufficient length to permit an impactor vertical drop of 3.05 m (10.0 ft) from its highest (cocked) position to its lowest at rest position. Thus the longitudinal axis of the impact chisel is 1.52 m (5 ft) from the axis of rotation of the pendulum arm. The pendulum is constructed from 5.1 cm (2.0 in) square aluminum tubing with a 0.32 cm (0.125 in) wall thickness as shown in figure 2.

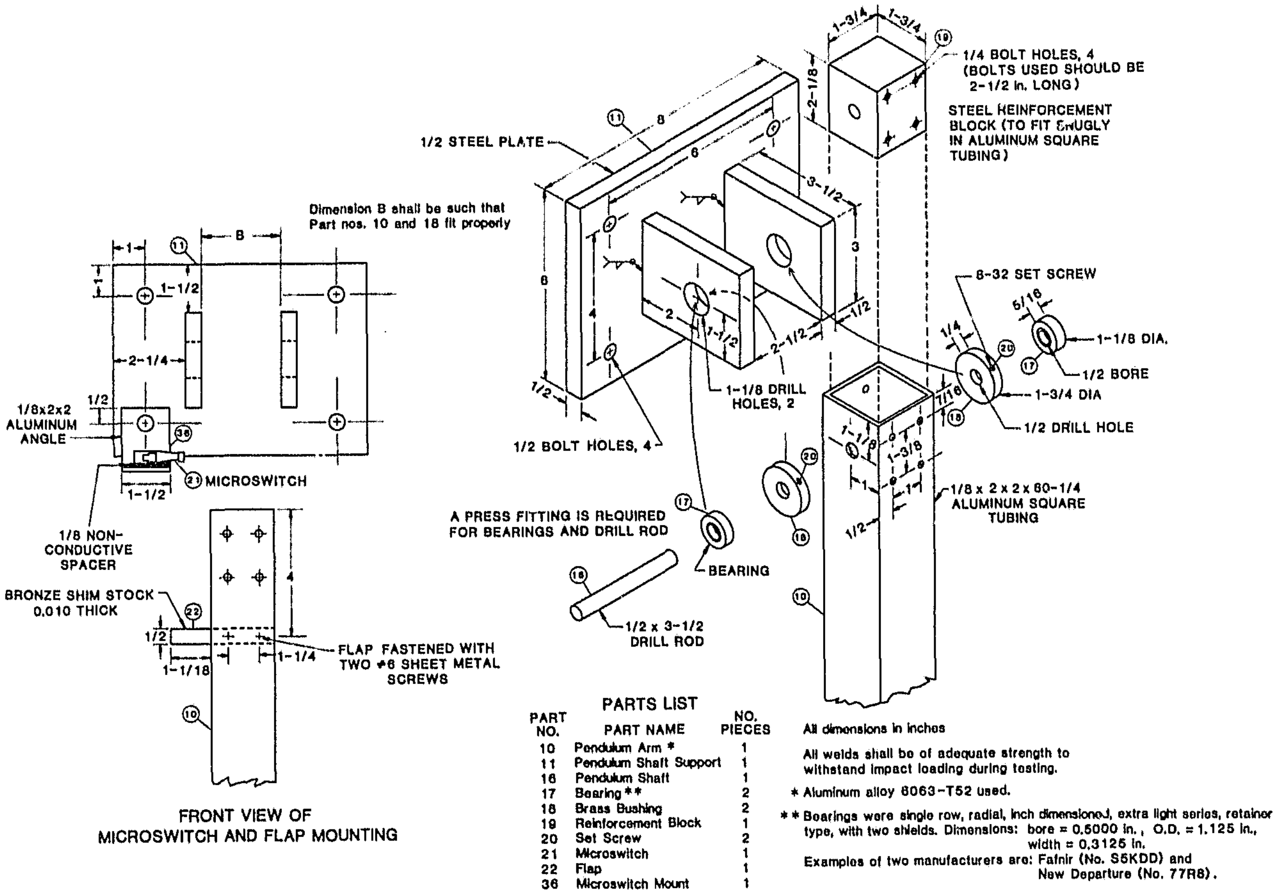


FIGURE 2. *Pendulum support system and upper section of pendulum arm.*

The pendulum arm requires a low-friction bearing pivot system, also shown in figure 2. It is critical that the pendulum arm swing through its arc with a minimum of lateral sway to ensure a reproducible impact location.

The construction details of the impact chisel housing and its attachment to the free end of the pendulum arm are shown in figure 3. The chisel housing permits a new chisel to be firmly installed for each specimen to be tested.

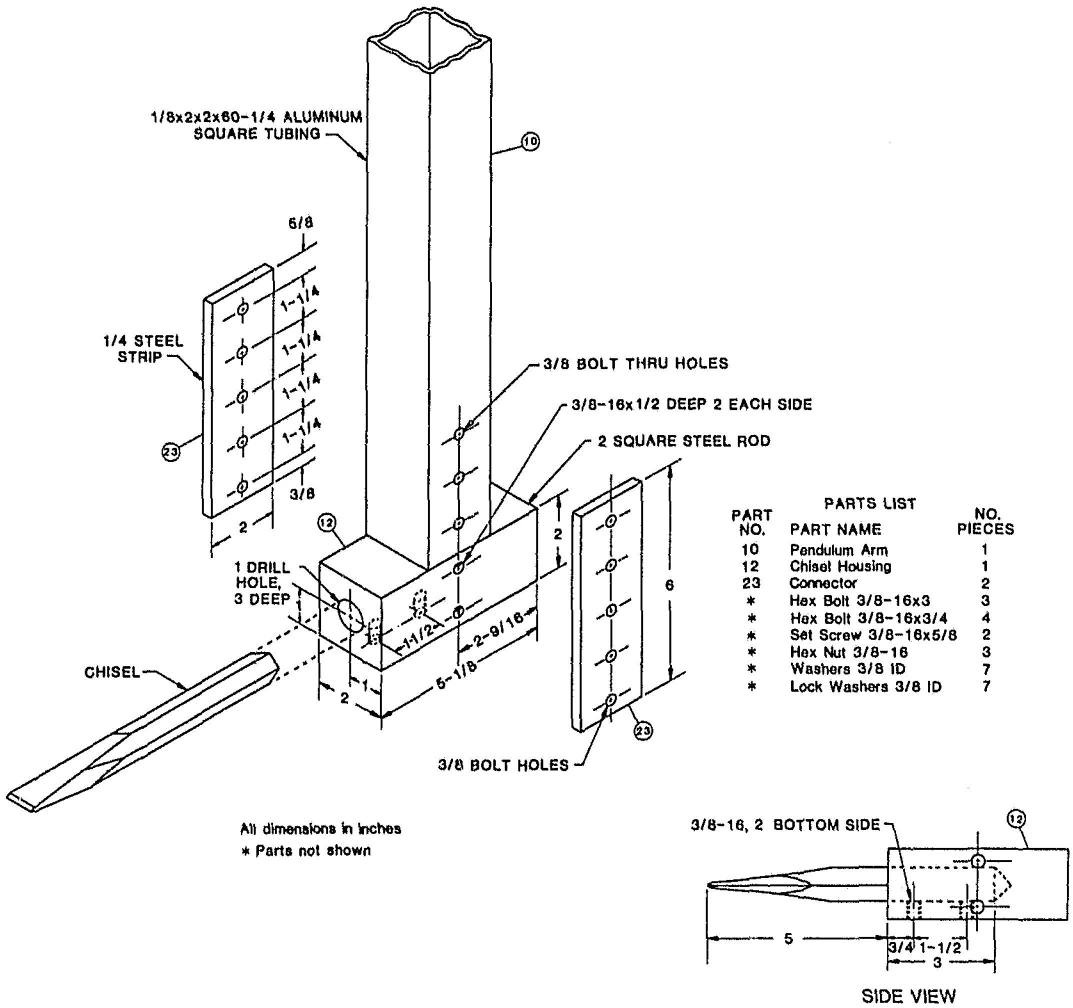


FIGURE 3. *Chisel housing assembly.*

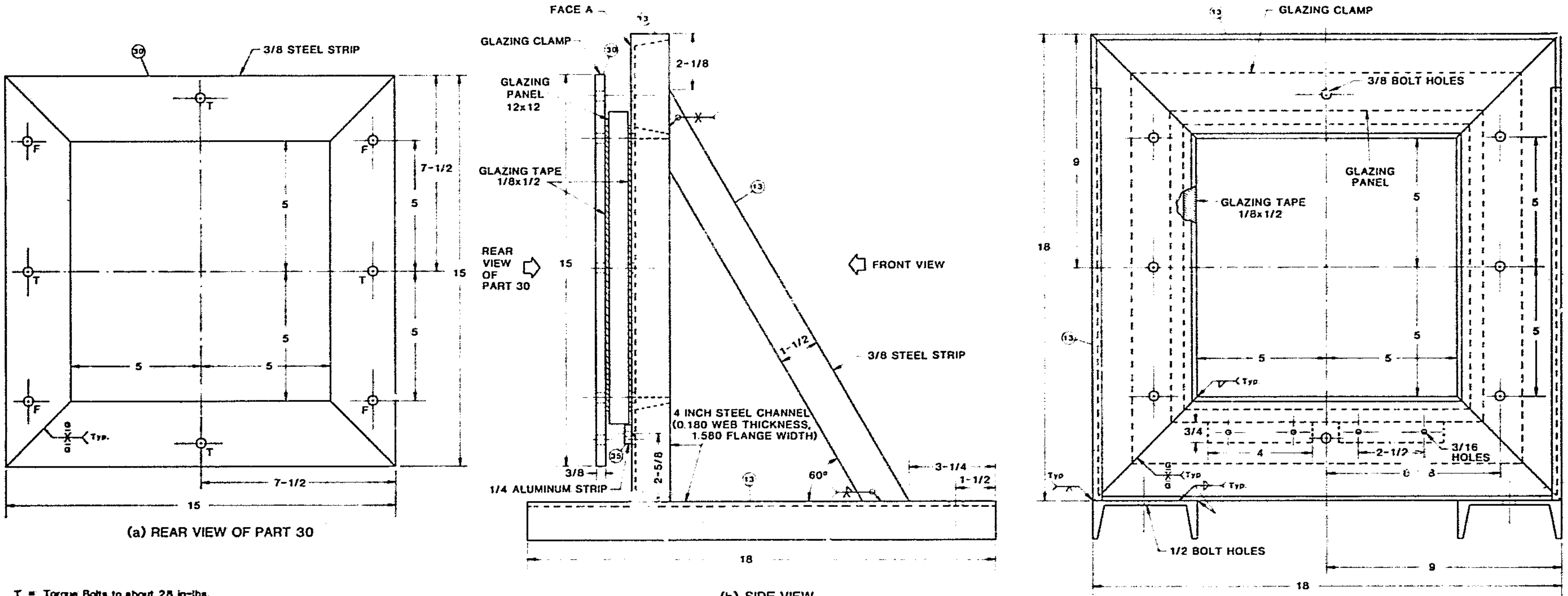
The test specimen is mounted in the glazing housing assembly shown in figure 4, between the glazing frame and the glazing clamp. The glazing frame, which provides a square opening of 25.4×25.4 cm (10×10 in) is constructed from 10.2 cm (4 in) steel channel welded to a rigid base. The glazing clamp, which also has a square opening of 25.4×25.4 cm (10×10 in) is constructed from 6.4 cm (2.5 in) wide steel strip, 9.5 mm (0.375 in) thick. The test specimen is held in place between the glazing clamp and the glazing frame by eight bolts.

The glazing housing assembly is securely attached to the pendulum support frame as shown in figure 5.

The impact chisel is a hexagonal-sided 20.3 cm (8 in) long steel chisel with a 2.54 cm (1 in) cutting edge conforming to the type IV requirements of Federal Specification GGG-C-313C [6].

The impact chisel shall have a length of 20.3±0.32 cm (8±0.125 in); shall weigh 590±45 g (1.3±0.1 lb); and the cutting edge shall be 90±2° to the longitudinal axis of the chisel. A new chisel shall be used for each test sequence.

The pendulum impact apparatus shall be constructed so that the maximum combined potential energy of the pendulum arm and chisel housing assembly with the chisel installed is converted into a kinetic energy of 149±4 N·m (110±3 lbf·ft), with a velocity of 8.0±0.2 m/s (26.3±0.7 ft/s) just before impact.



(a) REAR VIEW OF PART 30

(b) SIDE VIEW

(c) FRONT VIEW

T = Torque Bolts to about 28 in-lbs.
F = Finger Tighten Bolts (No Tools)
All dimensions in inches
All welds shall be of adequate strength to withstand impact loading during testing.

PARTS LIST

PART NO.	PART NAME	NO. PIECES
13	Glazing Frame	1
30	Glazing Clamp	1
35	Panel Seat	2

FIGURE 4. *Glazing housing assembly.*

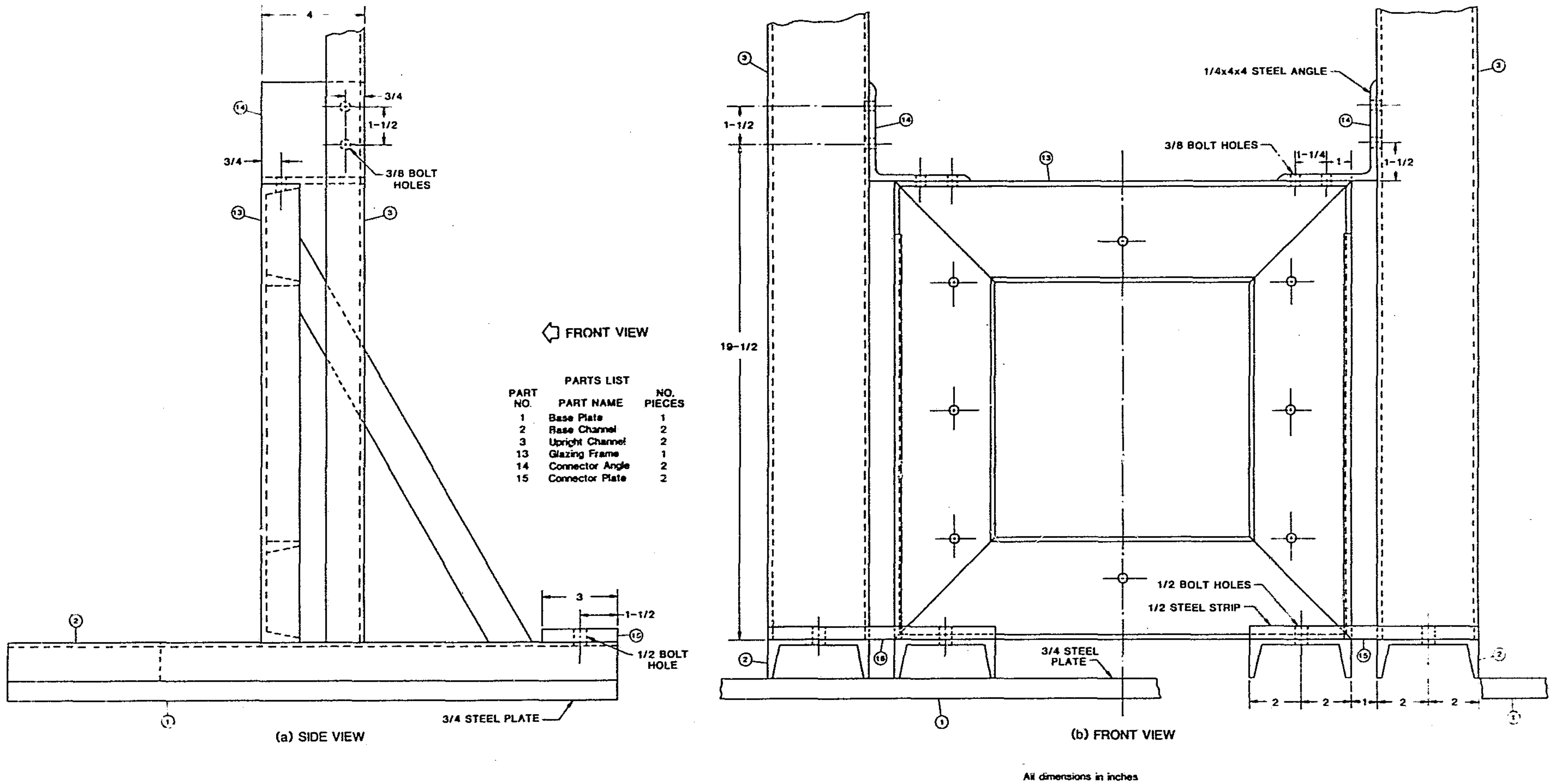


FIGURE 5. *Connection details for glazing frame.*

2.2 Heating Torches

During testing, the impact surface of the glazing specimen is subjected to flames from two torches constructed as shown in figure 6. Each torch consists of four 9.5 mm (3/8 in) copper tubes with nozzles [1.78 mm (0.070 in) orifices] mounted in an assembly securely attached to a vertical anchoring post. The four torches are mounted in pairs and spaced so that the orifices are located at the corners of a square having a side length of 2.54 cm (1 in).

The four torches of each of the two torch assemblies are connected to a manifold that is connected to a propane gas supply. Each torch assembly has its own in-line flowmeter to monitor its gas flow.

The torch assemblies are mounted on the pendulum support frame using anchoring posts as shown in figure 6. As shown in figure 6, the two torch assemblies are positioned such that the horizontal plane passing through the top orifices is 0.64 cm (0.250 in) below the center of the test specimen.

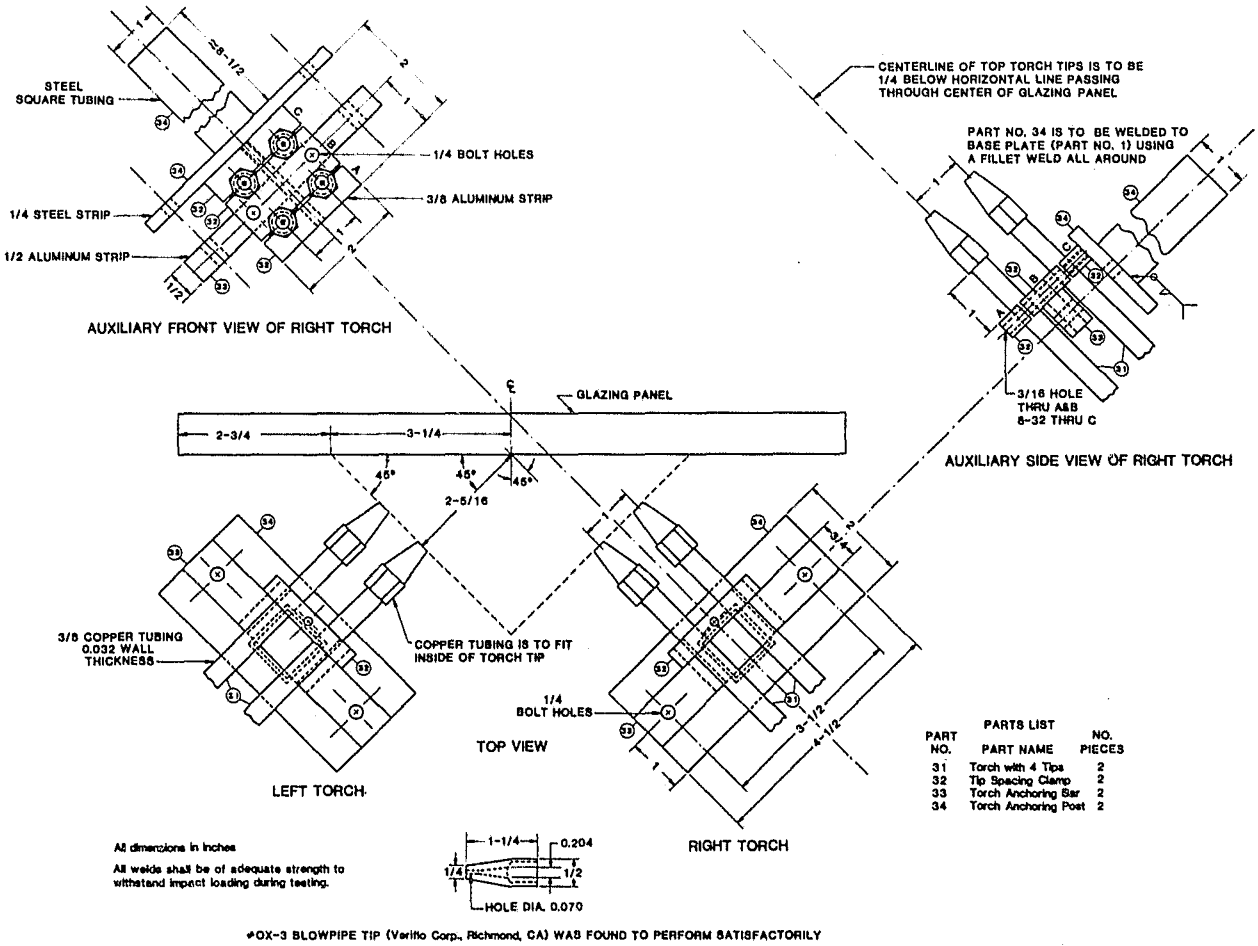


FIGURE 6. *Mounting and positioning of torches.*

2.3 Test Facility

The test facility shall be equipped with a large vented-hood of sufficient size to accommodate the test personnel, test apparatus and related instruments. The hood shall have sufficient capacity to provide an air velocity in the range of 4.6 to 9.1 m/min (15 to 30 ft/min) in the volume over the impact surface of the test specimen and the orifices of the torches when propane is not flowing through the torch assemblies with the test specimen mounted in place.

The test facility shall maintain a temperature of 20–30 °C (68–86 °F) and a relative humidity of 10–85 percent throughout the period of testing.

2.4 Instrumentation

2.4.1 Anemometer

A hot-wire anemometer is required to measure the air flow velocity over the impact surface of the test specimen with the hood vent in operation. The anemometer shall have an accuracy of ± 0.6 m/min (± 2 ft/min).

2.4.2 Gas Flow Meters

Two calibrated in-line gas flowmeters are required to regulate the propane gas flowing through each of the two torch assemblies. The flowmeters shall be adjustable to 0.27 ± 0.014 m^3/hr (9.5 ± 0.5 ft^3/h) at 21 °C (70 °F) and 760 torr (14.7 psi) absolute pressure using commercial-grade propane gas and shall maintain that flow rate throughout the test. Calibration shall be traceable to the National Bureau of Standards.

2.4.3 Event Recorder

A strip chart recorder is required to record the number and time history of impacts applied to each test specimen. The recorder shall have a chart speed of approximately 12.7 cm/min (5 in/min), accurate to within 2 percent. A voltage source compatible with the recorder input is connected to the recorder through a microswitch mounted on the impact apparatus to provide a spike each time the pendulum impacts the test specimen. In addition, a stopwatch shall be used to determine the total time that the specimen is exposed to the flame from the torches.

2.4.4 Velocity Measuring Device

An optically-activated chronometer is required to determine the velocity of the pendulum impact chisel just prior to striking the test specimen. This device must measure and display the time interval for the impact chisel to move between two points 3.81 cm (1.5 in) apart with sufficient accuracy to enable the determination of the velocity to within ± 15.2 cm/s (± 0.5 ft/s). The velocity shall be calculated as the distance between the two points [3.81 cm (1.5 in)] divided by the time required to travel that distance.

2.4.5 Audible Interval Timer

The time between impacts must be carefully regulated during each test sequence. An interval timer that can be reset to provide a specific time interval of 3.0 to 7.0 s is required. The timer shall produce an audible signal at the end of the time interval. The audible signal shall be of sufficient sound level to be clearly heard at a distance of at least 6.1 m (20 ft) during the impact testing.

3. SPECIMEN PREPARATION

The test specimens shall consist of 30.5 cm (12 in) square panels of the glazing material.

Inspect each test panel for flaws. In the event that a panel is obviously defective, discard it and select a replacement panel. Measure and record the length, width, and thickness of each panel and note this information on a data sheet. The following information shall also be noted on the data sheet:

a) Name of manufacturer.
b) Manufacturer identification number/name of the glazing material.
c) Month and year of manufacture.
d) A listing of the materials and their thicknesses that comprise the specimen, starting with the nonimpact surface.
e) Date of test and time of day test begins.

Establish a random test sequence for the test specimens, and number each panel accordingly. Record the test specimen number on a label affixed near one bottom corner of the panel on the side that will not be impacted.

4. TEST METHOD

4.1 Test Setup

Install the pendulum impact apparatus, with the glazing housing assembly rigidly attached to it, in a properly vented test facility. Insert an impact chisel into the chisel housing assembly with the cutting edge vertical. Make sure that the chisel is fully seated to the chisel housing assembly and tighten the screws that hold it in place.

Install the triggering components of the optical chronometer with the optical axis of each source/receiver pair perpendicular to the plane of the pendulum arc so that the impact chisel will interrupt both optical beams near the bottom of its arc, separated by a measured distance of approximately 3.81 cm (1.5 in). Position the on-trigger optical axis approximately 20 cm (7.75 in) from the glazing specimen impact surface, connect the trigger circuits to the chronometer and verify that the chronometer operates properly when the beams are interrupted.

Mount a 30.5 × 30.5 cm (12 × 12 in) panel of material known to withstand several impact blows from the pendulum impact chisel in the glazing housing assembly. The cutting edge of the chisel once installed in the chisel housing assembly shall either touch the impact surface of the panel or shall be within 0.64 cm (0.25 in) of the panel surface when the pendulum arm is at rest.

Connect the microswitch in series with the power supply to the strip chart recorder input terminals. Turn the recorder and microswitch power supply on, actuate the microswitch and adjust the recorder span and sensitivity such that the recording pen moves at least 20 percent of full scale when the microswitch is activated.

Turn the optical chronometer on and allow the electronics to warm up and stabilize if necessary. Adjust the chart speed of the recorder to approximately 2 mm/s (0.08 in/s) and actuate the chart drive. Raise the pendulum arm to its position of maximum potential energy (6° from the vertical, when held against the pendulum backstop, which is across the top of the pendulum apparatus frame) and reset the optical chronometer timing circuit. Release the pendulum arm and determine the chisel velocity immediately before impact. The velocity shall be 8.0 ± 0.2 m/s (26.3 ± 0.7 ft/s). Examine the strip chart recording to verify an event pulse has been recorded.

The velocity of the impact chisel shall be measured prior to the initiation of testing, and thereafter at the beginning of each testing day.

Attach the two torch assemblies and verify that they are securely mounted as specified in section 2.2.

Start the ventilation hood and allow the airflow to stabilize. Measure the airflow velocity near the torch orifices and the impact surface of the test panel with the hot-wire anemometer with no propane flowing through the torches. At each location, rotate the anemometer during the measurement to ensure that the maximum flow rate is measured. If necessary, adjust the airflow to obtain a velocity in the range of 4.6 to 9.1 m/min (15 to 30 ft/min).

Verify that the audible interval timer and the stopwatch function properly. Remove the nontest panel from the glazing housing assembly and remove the chisel from the chisel housing assembly.

4.2 Test Procedure

Install a new, unused, chisel in the chisel housing with the cutting edge aligned with the horizontal plane when the pendulum arm is at rest.

Attach two-sided self-adhesive glazing tape[2] to the surfaces of the glazing frame and the glazing clamp so that the inner edges of the tape coincide with the inner edges of the 25.4 cm (10 in) square openings in the glazing frame and glazing clamp. Position the test specimen on the two panel seats of the glazing frame with the impact surface toward face A (fig. 4), with the center of the specimen located at the center of the opening and press it against the glazing tape. Place the glazing clamp over the nonimpact surface of the test specimen, align its opening with that of the glazing frame, and press it against the test specimen. Install the eight bolts using lock washers and nuts. Tighten the nuts on the four bolts located on the horizontal and vertical center lines of the glazing clamp and glazing frame (see fig. 4) to 3.2 N·m (28 lbf·in) using a torque wrench. Tighten the remaining four bolts by hand without the use of tools. Once the glazing has been installed, testing must begin within 30 min.

Verify that the impact end of the chisel touches, or is within approximately 0.64 cm (0.25 in) of the impact surface of the specimen when the pendulum arm is hanging freely.

Turn on the gas supply valve to the two torch assemblies and adjust both flow rates to $0.27 \pm 0.014\ m^3/hr$ ($9.5 \pm 0.5\ ft^3/hr$) at 21 °C (70 °F) and 760 torr (14.7 psi) absolute, and verify that gas is flowing uniformly from all orifices. Having preset the flow rate, turn the gas valve supply off. The length of tubing between the flowmeters and torch assemblies should be kept to a minimum to prevent head loss, and care should be exercised to prevent kinking or other constriction of the tubing.

[2] The glazing tape [1/27 cm (1/2 in) wide by 3.1 mm (1/8 in) thick] shall be preformed, preshimmed butyl-polyisobutylene with a built-in continuous 1.7 mm (1/16 in) diameter synthetic rubber spacer rod located in the middle of the 1.27 cm (1/2 in) width. Tremco No. 440 glazing tape (Tremco, Cleveland, OH) or equivalent number have been found to be satisfactory.

Set the audible interval timer as appropriate for the operator controlling the impact pendulum and raise the pendulum arm to its uppermost position. Actuate the recorder chart drive. Turn the gas supply on and immediately ignite the torches using a prelit ignition stick (a long metal rod with a flammable material at one end).

Immediately upon ignition of the torches actuate the stopwatch and activate the audible interval timer. Release the pendulum arm when the signal from the interval timer is heard.

At the sound of impact, reset and start the audible interval timer, catch the pendulum arm upon rebound from the impact, and return it to the fully raised position. When the operator controlling the pendulum arm hears the signal from the audible interval timer, the pendulum is once more released and the audible interval timer is reset.

The test specimen shall be subjected to repeated impacts until the chisel penetrates through the test specimen; i.e., the end of the impact chisel clearly protrudes through the nonimpact surface of the test specimen.

The time interval between impacts shall be no more than 8.5 nor less than 5.5 s, and at least half of the time intervals shall be between 5.5 and 7.0 s for each specimen tested. Recognize, however, that precise control of the impact intervals is difficult to achieve, particularly when specimens are penetrated after only five or less impacts.

Upon penetration, stop the stopwatch, turn off the gas to the torches, and stop the strip chart.

Using protective gloves, remove the impactor from the test specimen immediately (to prevent the possibility of the chisel becoming permanently embedded in the glazing specimen), remove the test specimen from the glazing housing assembly, and then place the pendulum arm in the at rest (low potential energy) position. The total number of impacts as determined from the strip chart recording and the elapsed time displayed by the stopwatch shall be recorded on the data sheets.

5. DISCUSSION

Two individuals are required to implement the test procedure presented in this report, and teamwork is essential. It is not possible to specify the exact time setting for the audible interval timer to ensure that the impacts are spaced as required for this is dictated by the reaction times of the individuals controlling the interval timer and the pendulum arm. The test engineers that developed the test method found a time setting of approximately 5 s to be suitable for them.

The nature of the test is such that safety is a major concern and it is essential that anyone attempting to implement the test procedure establish and follow suitable safety procedures. Hard hats and safety shoes should be worn when assembling the impact apparatus. During testing, a mandatory clear zone must be established to ensure a safe distance around the full plane of the impactor pendulum arc and the flames from the torches. This is of particular concern during the presence of visitors and observers.

All test personnel must wear full face protection and hard hats. If there is any possibility that the test specimens can produce noxious gases when exposed to the flames from the torches, appropriate respiratory protection should also be used. The individual controlling the pendulum arm will have to operate from an elevated position. The nonskid ladder that is used must have nonskid stairs and be equipped with siderails. It is also important to light the torches as quickly as possible once the gas supply is turned on, for it would be possible to create an explosive gas mixture if the propane were allowed to flow freely for an extended time prior to ignition.

Both of the test personnel must be thoroughly familar with all aspects of the test procedure. During testing of a glazing specimen that resists a large number of impacts prior to penetration, it will be necessary for the person observing the glazing panel and operating the interval timer to change functions with the person controlling the pendulum arm. The changing of functions must be carefully coordinated and it is essential to take proper safety precautions, even if it results in extending the interval between impacts beyond the 8 s maximum specified in section 4.2.

The design of the pendulum impact apparatus is such that it should not be used to test glazing specimens that are thicker than 5.1 cm (2 in).

The tests that were conducted to develop the test method generally used a sample of two or three specimens of each type of glazing. This appeared to be a sufficient sample size in some cases. There were, however, some instances in which the scatter in the data for certain types of glazing was such that a larger sample size would be required to accurately characterize the penetration resistance of the glazing.

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[4] Physical security of window units. NIJ Standard-0316.00. National Institute of Justice, U.S. Department of Justice, Washington, DC 20531; 1980 August.

[5] Physical security of sliding glass door units. NIJ Standard-0318.00. National Institute of Justice, U.S. Department of Justice, Washington, DC 20531; 1980 August.

[6] Federal specifications for chisels, hand: cape, diamond point, cold, round nose, and side cutting. Fed. Spec. GGG-C-313C (GSA-FSS) dated August 16, 1976. General Services Administration, Washington, DC 20405.