INTERNATIONAL

Designation: F3664 – 24

Standard Practice for Blast Testing[1]

This standard is issued under the fixed designation F3664; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 *Purpose*—The primary purpose of this practice is to define good commercial and customary practice for conducting blast tests of physical security products, related devices, and systems. The goal is to harmonize results between test facilities and maximize the consistency and repeatability of the results obtained from these blast tests. This practice shall be used for blast simulator testing, where applicable.

1.2 *Objectives*—Objectives guiding the development of this practice are:

1.2.1 Formalize standard practices for conducting blast tests.

1.2.2 Facilitate high-quality, standardized results processing and reporting of test results.

1.2.3 Use as a starting point for a best practice standard that will grow into an industry standard both domestically and internationally.

1.2.4 It is anticipated that this practice will evolve over time as requirements and facility capabilities change.

1.2.5 This practice should not be considered the limit of requirements for proper completion of a given test program. There may be additional requirements depending on the application and the threat.

1.3 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.4 *Omissions*—The omission of any specific explosive, instrumentation type, material type, or test configuration does not necessarily preclude its use in accordance with this practice, as long as all applicable provisions are satisfied.

1.5 The following is a table of contents for this practice:

TABLE 1 Section Numbers and Titles

[1] This practice is under the jurisdiction of ASTM Committee F12 on Security Systems and Equipment and is the direct responsibility of Subcommittee F12.10 on Systems Products and Services.

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1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F1642 Test Method for Glazing and Glazing Systems Subject to Airblast Loadings

3. Terminology

3.1 This section provides definitions, descriptions of terms, and a list of acronyms for many of the terms used in this practice. These terms are an integral part of this practice and are critical to an understanding of this practice and its use.

3.2 *Definitions:*

3.2.1 *ammonium nitrate, fuel oil, ANFO, n*—a mixture of technical grade (TG) ammonium nitrate (AN) prills and fuel oil (FO), typically No. 2 diesel fuel; by mass, approximately 94 % AN and 6 % FO; a common, stable, and relatively inexpensive explosive commonly used for blast testing.

3.2.1.1 *Discussion*—Per 5.5, non-uniformity ANFO such as "clumping" or "caking" of the prills shall be considered as defects and shall not be used under this practice.

3.2.2 *authority having jurisdiction, AHJ, n*—organization, office, or individual having the responsibility to see that customer's or end user's requirements are properly addressed.

3.2.2.1 *Discussion*—The AHJ is the customer's technical representative having direct or delegated authority to represent the technical interests of the customer or end user. The AHJ works in cooperation with the test director during test planning, test execution, and test reporting.

3.2.3 *approved, adj*—acceptable to the authority having jurisdiction (AHJ).

3.2.4 *blast, n*—synonym for *explosion*.

3.2.5 *blast load, n*—load applied from a blast wave, which is described by the combination of pressure, impulse, and duration.

3.2.6 *blast simulator, n*—device or system using a high-energy source to generate a target pressure versus time having a positive phase shape, pressure, and impulse that replicates airblast pressure loads.

3.2.6.1 *Discussion*—A blast simulator may not be capable of producing an airblast negative phase pressure history.

3.2.7 *clearing effect, n*—clearing effect or "clearing" is a hydrodynamic phenomenon caused by blast pressure waves diffracting around the edges of a structure that in turn generates a relief wave propagating inward from the edges.

3.2.7.1 *Discussion*—The effect of these relief waves is to reduce the impulse placed on the structure.

3.2.8 *dynamic response, n*—deformation, stress, and other behavior of structure or structural element caused by the action of a time-varying loading while considering inertia, stiffness, and, in some cases, damping effects.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.9 *equivalent mass of trinitrotoluene (TNT), n*—one measure of the energy (power) contained in a given amount of a specified explosive expressed as the mass of TNT that would result in the same peak pressure or impulse, all other parameters being equal.

3.2.9.1 *Discussion*—A number generally ranging between 0.7 and 1.7. Note that, for some explosives, the equivalent mass can differ depending upon whether comparing peak pressures or impulses.

3.2.10 *explosion, n*—rapid chemical reaction that produces noise, heat, and a rapid violent expansion of gases.

3.2.11 *explosive, n*—material or device capable of causing an explosion under certain conditions, such as heat, shock, electrostatic discharge, or friction.

3.2.12 *explosive, adj*—relating to, characterized by, or operated by explosion.

3.2.13 *far range, n*—distance at which the blast loading from an explosion can be considered to be uniformly distributed over the tributary area of the element to be loaded.

3.2.13.1 *Discussion*—This is commonly accepted to correspond to a scaled distance, *Z*, that is equal to or greater than $1.2\frac{m}{kg^{1/3}}\left(3\ \frac{ft}{lbm^{1/3}}\right)$.

3.2.14 *fixturing, n*—devices or assemblies that may be used as interfaces between the test article and the test frame or reaction structure.

3.2.14.1 *Discussion*—Typically, the fixturing is intended to provide realistic local support conditions for the test article.

3.2.15 *generally accepted practice, n—in this practice,* corresponds to means or methods that are commonly known or generally accepted in the community of blast effects on structural devices and systems.

3.2.16 *impulse, n*—cumulative blast loading over time, calculated as the area under a pressure-time plot.

3.2.17 *near range, n*—distance at which the explosive is in close proximity to the test article relative to the size of the explosive, such that the resulting blast loading shall be considered to be non-uniformly distributed over the tributary area of the element being loaded.

3.2.17.1 *Discussion*—This is commonly accepted to correspond to a scaled distance, *Z*, that is less than $1.2\frac{m}{kg^{1/3}}\left(3\ \frac{ft}{lbm^{1/3}}\right)$.

3.2.18 *nonresponding, adj*—typically used to describe a reaction structure and test frame.

3.2.18.1 *Discussion*—Nonresponding is a term used to describe a support system wherein the response of the support structure does not influence the response of the tested article.

3.2.19 *range, n*—distance from the centroid of the explosive to a reference point on the targeted test article unless otherwise specified by the AHJ; see Fig. 1.

3.2.20 *reaction structure, n*—structure used to support the test article, test frame, and fixturing during the blast event.

3.2.20.1 *Discussion*—The reaction structure normally has large mass and stiffness compared with the anticipated loading and response of the test article. Examples include reinforced

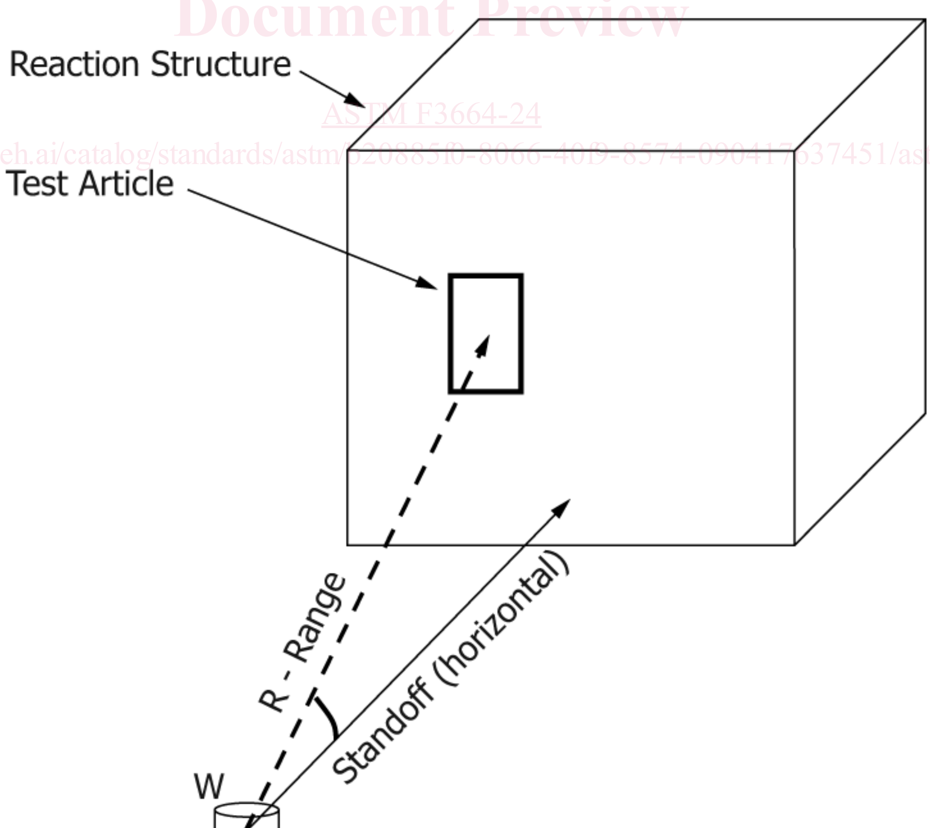

FIG. 1 Range and Standoff

concrete boxed-shaped rooms, reinforced concrete culverts, or containers filled with soil positioned behind the test frames. Another example may be a test frame mounted to a sled with the sled held in place by concrete blocks or possibly sandbags.

3.2.21 *rigid, adj*—used to describe a structural component or system that has very high strength and very small deformations or deflections relative to the loading and, accordingly, has a very small effect on the response of the test article.

3.2.22 *scaled distance, Z, n*—ratio of the range to the cube root of the explosive charge size as an equivalent mass of TNT, which commonly serves as the basis for determining the blast loading parameters.

3.2.23 *standoff, n*—the horizontal distance between a reference plane on the reaction structure to the explosive device's reference point which shall be the centroid of the explosive device, unless otherwise defined by the AHJ; see Fig. 1.

3.2.23.1 *Discussion*—Typically, the standoff is measured to the center of the charge. As there may be exceptions, it is important that the standoff be clearly defined in the test plan. Additionally, the position and orientation of each test article relative to the charge location must be defined.

3.2.24 *test article, n*—device or system being tested or evaluated.

3.2.25 *test director, n*—person representing the test performer or test facility charged with overseeing and directing test planning, execution, and reporting.

3.2.25.1 *Discussion*—Test director usually acts as the point of contact for and works in cooperation with the AHJ.

3.2.26 *test facility, n*—physical infrastructure, equipment, items, and devices required for the execution of blast tests including geographical area (blast range), reaction structure, instrumentation, equipment, tools, power sources, and the like.

3.2.27 *test frame, n*—typically used as a means of structural connection between the test article and the reaction structure.

3.2.27.1 *Discussion*—Test frames are typically constructed from either reinforced concrete or steel assemblies. An example would include a tilt-up reinforced concrete wall placed in front of and rigidly attached to a reaction structure. The test article may be attached directly to the test frame or there may be fixturing included to serve as the interface between the test frame and the test article.

3.2.28 *test performer, n*—organization, company, or laboratory charged with the task of planning and executing the test(s) and producing the appropriate deliverables related to test(s).

3.2.28.1 *Discussion*—The test performer may include personnel associated with the test facility.

3.2.29 *test plan, n*—formalized plan, in writing, detailing the objectives, resources, and process(es) for a specific test to be created and approved before a test occurs, preferably well in advance of said test.

3.2.30 *witness panel, n*—panel placed on the protected side of a test article that is used to document spall or fragmentation typically from a test article containing glazing.

3.3 *Acronyms and Symbols:*

3.3.1 *AHJ*—Authority having jurisdiction

3.3.2 *ANFO*—Ammonium nitrate, fuel oil

3.3.3 *DAQ*—Data acquisition system (also known as DAS)

3.3.4 *R*—Range distance from centroid of the explosive to a point on the test article, m (ft)

3.3.5 t_d—Duration of positive phase, ms

3.3.6 *TNT*—Trinitrotoluene

3.3.7 U_s—Shock front velocity, m/ms (ft/ms)

3.3.8 *W*—Explosive mass as an equivalent quantity of TNT, kg (lbm)

3.3.9 *Z*—Scaled distance $Z=\frac{R}{W^{1/3}},\frac{m}{kg^{1/3}}\left(\frac{ft}{lbm^{1/3}}\right)$

4. Significance and Use

4.1 This practice shall be followed for blast testing with an aim toward maximizing the consistency and repeatability between blast tests and test facilities. Specific requirements include test configuration, instrumentation, test result processing, data reductions, facility requirements, clearing effects, and fixturing or reaction structure design.

4.2 In this practice, inconsistencies in blast testing methodology are reduced and blast testing reporting (interpretation and documentation of blast results) is standardized. This improved consistency of practice will facilitate direct comparison of results, testing repeatability, and identification of trends.

4.3 This practice shall apply to blast simulator testing where applicable, including all aspects of the specification except those that are specific to open air explosive testing.

4.4 *Uses*—This practice in total is required for open air blast tests and applicable sections are required for blast simulator tests. Any deviation or exception to the practice should be addressed as early in the planning stage as possible and shall require written approval by the AHJ.

5. Test Facility Requirements

5.1 *Topography*—The topography immediately adjacent to the location of the explosive charge shall be approximately level (0.3 m (1.0 ft) rise or fall in 30 m (100 ft)) from the charge to 25 % of the standoff past the target, within an arc encompassing 30° on either side of the reaction structure. Additionally, the area outside the arc shall be clear of any geometrical shapes or items that may inadvertently cause reflective or secondary loads on the target. Grade slope and reflecting surface behind the charge should be avoided.

5.2 *Camera Vantage Points*—The test range shall provide sufficient camera vantage points situated to have an unobstructed view of all active test (reaction) structures and the charge location. The vantage point(s) shall be sited so as to offer a side view of the hemispherical blast wave striking the front of the test (reaction) structure, with at least one camera for each active test (reaction) structure. The blast test plan may dictate other additional camera vantage points to provide other views.

5.3 *Blast Pad for Open Airblast Testing*—Beneath the charge location, a blast pad shall be provided to minimize the influence of the local soil or substrate, or both, on the blast test results. The blast pad shall consist of either a concrete slab, or a steel plate, or a combination of both. The blast pad shall completely bear upon firm in-situ soil or fill material. The top face of the blast pad shall not protrude more than 50 mm (2 in.) about the surrounding grade. In cases of repeated tests, blast pads may be reused with careful evaluation of condition after each test. An exception to requiring blast pads may be considered in cases in which extremely hard and durable substrate is within 300 mm (12 in.) of the surface under the charge (shallow bedrock as an example).

5.3.1 *Concrete Pads*—Concrete pads shall be normal-density concrete and shall have a 28-day compressive strength of no less than 20.7 MPa (3000 psi). Unless directed otherwise by the AHJ, the concrete pad shall be 2.44 m by 2.44 m by 0.23 m (8 ft by 8 ft by 9 in.). Concrete blast pad reinforcement requirements are the responsibility of the test performer but shall be a minimum of 9.5 mm rebar spaced at 0.46 m each face and each way (#3 rebar spaced at 18 in. each face and each way).

5.3.2 *Steel Plate*—Unless directed otherwise by the AHJ, the steel plate shall be 2.44 m by 2.44 m (8 ft by 8 ft) with a minimum thickness of 25 mm (1 in.). It shall be made in one piece (by welding plates together if required) and shall be made of mild steel (ductile steel).

5.4 *Signal Noise*—All powered equipment at the test range, whether at the cameras, sensors, data acquisition system, or in the control bunker, shall be supplied with "clean" filtered power, such that sensor signals are not cluttered with extraneous electrical noise. Specifically, it is recommended that the pre-trigger signal noise for sensors be less than 1 % of the sensor range. A portable option includes generators with built-in inverters.

5.5 *Handling of Explosives*—The test performer shall have written procedures for handling, storing, tracking, and disposing of explosives. Minimum record maintenance should include purchase or shipment: the purchase date, lot number, vendor name, and specific technical information regarding explosive yield. For ANFO, non-uniformity of the product such as "clumping" or "caking" of the prills shall be considered as defects and shall not be used under the scope of this practice. Unless specified by the manufacturer, the use-by date for ANFO is defined as six months from date of purchase and not to exceed nine months from the date of manufacture.

6. Instrumentation

6.1 *Applicable Instrumentation*—Instrumentation requirements may vary considerably based on the nature of the test article and the load condition of interest. A given test may include more than one test article. This section provides general guidance for instrumentation sensors, devices, and systems as they are applicable to a given test.

6.2 *Pressure Transducers*—Pressure transducers shall be provided in accordance with Test Method F1642. Additionally, pressure gauges shall be mounted so as to minimize localized clearing effects (for example, mounted flush with the face of the reaction structure) and structural-response-induced noise (see also 6.12). Techniques that involve covering the front of the gauge with soft materials such as tape or silicone grease may be used to mitigate extraneous noise, if accompanied by clearly documented evidence that the technique does not significantly affect the pressure wave measurement.

6.3 *Displacement Measurements*—Displacement measurements may be obtained by some combination of the following devices or methods. In general, displacement gauge accuracy, measured range of movement, and sampling rate should be selected in accordance with the predicted movements of the tested device. General comments regarding application and challenges include those in 6.3.1 – 6.3.6.

6.3.1 *Optical/Laser Gauges*—Gauges may be used in cases in which debris and dust do not interfere with the signal. Excessive movement of the measurement point may also cause the signal to be lost mid-test. Flash from explosive detonation may also need to be addressed to avoid interference with proper signal. This is typically accomplished by covering any transparent test specimen with an opaque covering.

6.3.2 *Rod Deflection Potentiometers*—Rod deflection potentiometer gauges (rack and pinion gauges) are typically used in blast testing, especially where there is considerable dust and debris. Concerns include attachment of the rack to the test article, column buckling of the rack, and whip of the rack during the response. Attachment of the rack to the tested article shall not damage the article (particularly in the case of glass) and shall provide for displacement measurement through inbound and outbound response of the tested article. The rack shall be stiff enough to minimize buckling, lateral whip, or both, that can affect displacement measurement. The mass of the rack should be as small as practicable so as to minimize the possible effect on dynamic response of the tested article.

6.3.3 *String Potentiometers*—String potentiometers (cable-extension position transducers, also known as yo-yo gauges) may be used with the caveat that the rate of cable recoil is limited to a maximum acceleration. Exceeding that acceleration can result in measurement error or, in the case of backlash, total measurement loss. The device is sensitive to small debris and dust, interfering with the cable movement or introducing extraneous cable movement, or both, thereby affecting the displacement measurement.

6.3.4 *Accelerometers*—Accelerometers (discussed in 6.4) may be used to measure acceleration at key locations with displacements calculated via numerical integrations to calculate velocity and displacements. The results are typically useful to "scale" movements and serve as backup to other direct measurements.

6.3.5 *Global Movement of Reaction Structure*—The global pre- to post-test movement of the reaction structure shall be measured relative to a fixed reference. The intent is to document net movement caused by sliding or shift of the structure, resulting from the applied blast load. The measurement accuracy shall be within ±3 mm (±⅛ in.).

6.3.6 *Other Displacement Measurements*—Various other techniques may be used such as fiducial markers coupled with high-speed cameras, strain visualization, or other techniques as approved by the AHJ. A completely different technology involves piezo pin sensors that may be used to measure global displacements, by activating when contact is made with the piezo material in the tip of the pin. In blast application, the pins are typically destroyed. In all cases, there shall be well-documented evidence regarding the efficacy of the method.

6.4 *Acceleration Measurements*—Accelerometers may be used to characterize response versus time for the tested device or the reaction structure. Care should be taken regarding general issues such as sensitivity, amplitude range, decay time, drift, and mounting (see also 6.12). It is crucial that the linear frequency range of the accelerometer encompasses the primary response frequencies of the tested device coupled with the reaction structure.

6.5 *Direct Force Measurement*—Direct force measurement may be obtained through strain measurements of key structural components or implementation of load cells.

6.5.1 *Load Cells*—In the case of load cells, the range and sensitivity of the load cell shall capture the force response over both the inbound and outbound portions of the response. Accordingly, any preload applied before the load event shall be large enough to account for rebound loading. A critical consideration is the mounting of the load cell (see also 6.12). Any residual permanent displacement that may influence the accuracy of the load cell force measurement shall be limited to less than 5 % of the gauge displacement corresponding to the maximum force measured.

6.6 *Strain Measurement*—Strain measurements are most reliably obtained using strain gauges mounted directly to structural components (see also 6.12). The selection of the gauges shall include consideration for the material and surface being instrumented as well as the range and linearity of strain values. Particular care shall be taken when strains exceed the elastic limit of metals. In all cases, the strain gauges shall be selected, installed, protected, and instrumented in accordance with generally accepted practice and the gauge manufacturer's recommendations. Optical strain measurement and strain visualization techniques may be used when supported by well-documented evidence regarding the effectiveness of the techniques in applications similar to the planned test.

6.7 *Temperature Measurement*—Temperatures of the tested device may be measured using suitable devices including thermocouples, infrared camera, and the like. The primary concern is that key tested article temperatures are measured and recorded as close as possible to the time of detonation.

6.8 *Photographs*—Digital photographs shall be taken with a camera having a minimum resolution of 8 megapixels.

6.9 *Video*—Various videos may be required using a combination of color, black and white, real-time, high-speed, and disposable cameras. In this context, a high-speed camera shall have a frame rate of no less than 1000 frames per second (fps). For external views, the frame rate shall be fast enough to capture the movement of the shock wave. High-speed video shall include a time counter on the video suitable for measuring time steps between frames. The time counter on all videos shall reference time zero (0:00) from time of detonation unless otherwise specified. The test performer shall ensure that the video recording equipment has the capacity to capture the full event as predetermined in cooperation with the AHJ and in accordance with 9.4.

6.10 *Witness Panel*—A witness panel is typically required as a means of qualifying and quantifying the amount of fragmentation that either passes or is expelled from the tested article. The specific materials of construction and configuration of the witness panel shall be documented in the test plan and report.

6.11 *Redundancy and Correlation*—As much as practicable, a variety of gauges or gauge types shall be used to provide redundancy, particularly in cases in which gauges or gauge signals may be lost during a test. Correlation between, for example, accelerations and global movements or strains and displacements, may be facilitated through careful selection and placement of gauges.

6.12 *Mounting Cameras and Sensors*—Cameras and sensors shall be supported or attached in such a manner as to minimize spurious dynamic movements that may clutter or bias images or data.

6.13 *DAQ*—The DAQ shall consist of a digital recording system with a sufficient number of channels to simultaneously accommodate the desired number of sensors and transducers. The DAQ shall operate at a sufficiently high frequency to record the peak positive pressure reliably. The DAQ shall also incorporate filters to preclude alias frequency effects on the data.

6.14 *Calibration and Validation:*

6.14.1 *Calibration*—All sensors (pressure, deflection, acceleration, and so forth) shall have been calibrated in accordance with the test performer's standard practice. The calibration standard practice shall be submitted with the test plan for review by the AHJ. The test performer's standard practice and calibration records shall be included as an annex to the test report.

6.14.2 *Pre-Test Check of Instrumentation*—Bench top, or similar, testing of sensors and instrumentation shall be performed before but not to exceed six months before the test time. The results shall be compared against standard signals or measurements to demonstrate a consistency within 2 % of the standards. Sensor connectivity tests shall be performed immediately before the event. Documentation of the pre-test check shall be available to the AHJ before the test and shall be included with the final report. Results shall be reviewed by the test performer between tests to ascertain validity of the data.

6.14.3 *Modifications to Test Plan*—The AHJ shall be notified of any modifications to the test plan as well as changes to instrumentation and test article condition as soon as practicable. There shall be as much notice as practicable for evaluation of the possible impact on results. If there is the potential for any impact on the results, then the test may need to be rescheduled until the issue can be remedied.

7. Reaction Structure

7.1 *Nonresponding Structure*—The test article (device or system) shall be supported by a structure deemed as nonresponding. Ideally, in numerical terms, the maximum dynamic displacement of any and all interface points between the test article or fixturing connection to the test frame and the reaction structure shall be limited to 5 % of the maximum displacement of the tested article (see also 6.3.5). Alternatively, the period of