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DISERTACIÓN PREVIA A LA OBTENCIÓN DEL TÍTULO DE INGENIERO CIVIL

“ANÁLISIS COMPARATIVO ENTRE ENSAYOS DESTRUCTIVOS Y NO DESTRUCTIVOS DE LA RESISTENCIA DEL HORMIGÓN CON DIFERENTES MÉTODOS DE DOSIFICACIÓN”

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I. Dedicatoria

Primeramente, a Dios por darme la sabiduría y fuerza para haber llegado a culminar esta etapa de mi vida y de mi carrera.

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1. Generalidades

1.1. Introducción

Durante años se ha buscado garantizar que el hormigón cumpla con su resistencia de diseño en obra dentro de la carrera de ingeniería civil. Este se lo lleva a cabo mediante ensayos destructivos. Comúnmente se utiliza el ensayo a compresión simple del hormigón el cual consiste en realizar muestras cilíndricas que son sometidas a una carga axial hasta su rotura y por medio de esta carga determinar la resistencia de dichas muestras (Robinson Builes Salazar, 2016; Tomas Israel Vallejo Garcia, 2016).

Ya que la ciencia avanza cada día, se vienen implementando nuevas tecnologías que ayudan a facilitar estos procesos, a partir de los cuales se han creado métodos no destructivos (Robinson Builes Salazar, 2016; Tomas Israel Vallejo Garcia, 2016).

Tomas Israel Vallejo Garcia (2016) afirma: “Los métodos destructivos son aquellos que se encargan de analizar el comportamiento del hormigón, por su capacidad de soportar esfuerzos físicos de una muestra tales como: esfuerzo a compresión y tracción” (p 1). Son, por tanto, estos los más utilizados y con los resultados de mayor confiabilidad.

En cambio, los métodos no destructivos se definen como una prueba, examen o evaluación que se realiza sobre cualquier muestra de ensayo, por medio del cual no se busca cambiar o alterar sus propiedades físicas o químicas, con el fin de determinar su resistencia o la presencia de discontinuidades que puedan afectar la utilidad de dicha muestra (Charles hellier, 2003).

Este proyecto investigativo tiene como fin comparar los resultados obtenidos en los ensayos destructivos y no destructivos, para luego encontrar una relación entre estos que permita obtener una ecuación estadística por medio de la utilización de muestras realizadas por los estudiantes que cursaron el 3er nivel de Ingeniería Civil en la materia de Laboratorio de Hormigones, las que fueron ensayadas a los 7 y 28 días para obtener su resistencia máxima.

El ensayo destructivo utilizado en este proyecto fue la compresión simple de cilindros del cual se obtiene el esfuerzo máximo que soporta el hormigón. Mientras que los ensayos no destructivos empleados fueron el esclerómetro (Martillo de Rebote) y el ultrasonido que dan como resultado un índice de rebote y una velocidad de propagación de onda, respectivamente. La decisión de utilizar los aparatos mencionados para la realización de los ensayos no destructivos se basa en que se han convertido en una herramienta fundamental para determinar la resistencia y la calidad del hormigón endurecido.

Cabe recalcar que en ningún concepto los ensayos no destructivos de la resistencia del hormigón podrán reemplazar a los ensayos destructivos, pero son usados para obtener una referencia de donde se encuentra el problema de la estructura y para darnos una idea de la resistencia, como la calidad del hormigón por medio de correlaciones entre estos dos ensayos.

En los siguientes capítulos se dará una explicación más amplia sobre cada uno de los ensayos utilizados.

1.2. Antecedentes

Es imposible identificar una fecha específica que indique exactamente cuando comenzaron las pruebas no destructivas tal como las conocemos hoy en día. Se puede señalar que el inicio de estas pudo haber sido en 1950 y se han ido desarrollado hasta la actualidad, experimentando cambios, innovación y crecimiento sin precedentes a través de nuevos instrumentos y materiales (Charles Hellier, 2003).

La base para la utilización del ultrasonido que conocemos en la actualidad se ubica sobre el análisis de los procesos relacionados con la propagación de ondas en sólidos, los cuales comenzaron en los años 50s. También en este mismo año, el martillo de Schmidt o esclerómetro fue creado e incluido en el mercado por el investigador Ernst O. Schmidt y Proceq. Sin duda estos dos instrumentos de ensayos no destructivos son los más utilizados para la evaluación rápida de la condición de estructuras de hormigón (Castillo, 2015; Masco, Fernandez, Monteville, Mamani, & Vargas, 2017).

1.3. Justificación

Para poder justificar y entender la importancia de la investigación, será necesario explicar los antecedentes de un caso donde se observaría la necesidad de estos equipos no destructivos en la estimación de resistencia en el sito, ya que estos nos dan una respuesta rápida que permite tener una idea de las condiciones del hormigón y así evitarnos sacar núcleos sin saber el lugar donde mayor daño sufrió la estructura.

Ante los eventos pasados en el terremoto del 16 de abril del 2016 cuya magnitud fue de 7.8 y epicentro, en la ciudad de Pedernales, el Gobierno Nacional decidió implementar un plan el cual busca la reconstrucción de las estructuras afectadas en la zona de la costa, prometiendo minimizar la vulnerabilidad de estas y lograr una mejor capacidad de respuesta en la población (ZUMBA AGUIRRE, 2017).

Estas estructuras deben cumplir con la nueva norma de estructuras sismo resistentes NEC-SE-DS (Peligro Sísmico) implementada en el mismo año, la cual nos da una mayor seguridad al momento de construir.

Al hablar de reconstruir resulta necesario realizar exámenes de patología de las estructuras y en estos casos debemos utilizar ensayos no destructivos, como el esclerómetro y el ultrasonido, conocidos como los mejores para medir la calidad del hormigón. Además, se pueden correlacionar con el objetivo de obtener resultados de resistencia y detectar las zonas con mayores fallas para la optimización de extracción de núcleo.

Al ver esto, y teniendo en cuenta la falta de información al respecto, el objetivo principal de este proyecto de titulación es correlacionar los datos obtenidos por el esclerómetro y el ultrasonido que aportan como respuesta el índice de rebote y velocidad de propagación de onda en el hormigón respectivamente, con los resultados de la compresión simple de cilindros de 15x30 cm de hormigón.

El ensayo se ejecutó a los 7 y 28 días, en el “Laboratorio de Materiales” de la Pontificia Universidad Católica del Ecuador, con probetas realizadas por los estudiantes del 3er nivel de Ingeniería Civil 2019-02, en la materia de “Laboratorio de Hormigones” y adicionalmente se ensayaron 20 cilindros proporcionados por la hormigonera HOLCIM, para poder así recolectar la suficiente información de resistencia obtenidas en cada una de las pruebas que esta comprende.

Viendo la necesidad de estas nuevas alternativas frente a la optimización de materiales y desperdicios, se hace imprescindible la utilización de ensayos no destructivos y es por ello por lo que se busca lograr una correlación de estos con los ensayos destructivos, para poder entender un poco más su uso, obtener resultados y que estos sean utilizados para futuras investigaciones.

Algunos se preguntarán por qué se decidió hacer ensayos a los 7 días, si la superficie del hormigón a esta edad es parcial o totalmente húmeda y el esclerómetro no se puede utilizar en estas condiciones. Basándonos en la norma ASTM C805 (2016a) en la nota 8: “La superficie de concreto seco da mayor número de rebote que en la superficie húmeda” (p 2), claramente no nos prohíbe el utilizarlo en superficies húmedas y en el manual de usuario del equipo Test Concrete Hammer R-7500 nos da valores de corrección para superficie seca, medianamente húmeda y húmeda, estos serán presentados más adelante (Kamekura Seiki Co., 2016).

1.4. Alcance

El presente proyecto contempla la comparación de ensayos destructivos (Compresión simple) y no destructivos (Ultrasonido (Velocidad de propagación) y Esclerómetro (Índice de rebote)) con diferentes métodos de dosificación (Al peso, al volumen y con aditivo) de hormigón realizados por los estudiantes que están cursando la materia “Laboratorio de hormigones” perteneciente al 3er nivel de Ingeniería Civil de la Pontificia Universidad Católica del Ecuador.

1.5. Objetivos General

Comparar ensayos destructivos y no destructivos con diferentes métodos de dosificación para encontrar una correlación entre los resultados que se obtienen de estos estudios.

1.6. Objetivos Específicos

- Obtener resultados de resistencia de las muestras realizadas por los estudiantes que están cursando el tercer nivel en la materia de “Laboratorio de Hormigones” de la Pontificia Universidad Católica del Ecuador.
- Obtener los resultados de los cilindros de hormigón a los 7 y 28 días utilizando los equipos: Concrete Hammer Tester R-7500 (Esclerómetro), Elsonic ESI-10 (Ultrasonido).
- Obtener resultados de la resistencia de compresión simple de los cilindros de hormigón a los 7 y 28 días.
- Realizar correlaciones de los resultados entre los equipos anteriormente nombrados y los resultados obtenidos por el ensayo de compresión simple de los cilindros de hormigón.

1.7. Tamaño de muestra

Para determinar el número de muestras se realizó un cálculo estadístico mediante la siguiente fórmula:

$$n = \frac{Z_a{}^2 * p * q}{d^2}$$

(Administración, 2017)

Donde:

n: Tamaño de la muestra

Za: Nivel de confianza

p: Probabilidad de éxito o porción

q: 1-p (Probabilidad de fracaso)

d: Precisión (error máximo admisible en términos de porción)

En este caso se decidió utilizar los siguientes valores para cada una de las variables identificadas:

Existen diferentes valores para el nivel de confianza (Za):

- Para una seguridad de 95%, Za= 1.96
- Para una seguridad del 99%, Za=2.58

En el siguiente estudio se decidió utilizar un nivel de confianza del 95% considerada aceptable para esta investigación.

Con relación al aspecto precisión (d) se resolvió emplear un valor para los 7 y 28 días de 6% debido a que es considerado un error aceptable.

Respecto a la porción (p) se recomienda usar un 5 % debido a la gran incertidumbre que existe al trabajar con hormigones simples. Así como para q=1-p en este caso q=1-0.05= 0.95.

A partir de esto obtuvimos los siguientes resultados:

$$\mathrm{n} = \frac{1.96^2 * 0.05 * 0.95}{0.06^2} = 51 \text{ muestras}$$

Este resultado es para los 7 y 28 días, cumpliendo con el número de muestras ensayadas de 70 para cada uno de los períodos.

Para la cantidad de cilindros proporcionados por la Hormigonera Holcim consideramos que 20 muestras serían suficientes ya que estas son hechas con rigurosos controles de calidad.

2. Marco Teórico

2.1. Dosificación:

Dosificar una mezcla de hormigón, es determinar la combinación apropiada de los agregados (grueso y fino), cemento, agua y en ciertos casos los aditivos; con el fin de producir una mezcla con el grado requerido de manejabilidad, resistencia deseada y durabilidad necesaria para el tipo de construcción en el que se vaya a utilizar.

La determinación de una dosificación para hormigones debe hacerse partiendo de unos datos iniciales establecidos en base al proyecto y condiciones de ejecución (reales o previstas) de la obra. Como datos necesarios se pueden indicar, por orden de trascendencia, los siguientes:

- Resistencia de diseño
- Sistema de puesta en obra o consistencia del hormigón
- Características de los materiales como el cemento, granulometría, peso específico, procedencia o forma de los agregados.

Existen 3 tipos de dosificaciones:

2.1.1. Dosificación al peso

Este método se basa en la relación agua/cemento, granulometría, módulo de finura, tamaño máximo y tamaño máximo nominal del agregado y el pasante del tamiz número 200. Este nos ayuda a determinar el peso necesario de agregados (fino y grueso), cemento y agua el cual se deberá utilizar para la mezcla diseñada.

Este método de dosificación es utilizado como base para los otros métodos tal como la dosificación al volumen y la dosificación al peso con aditivo.

Las proporciones se calculan con la siguiente formula:

$$Cemento : Agregado\ fino : Agregado\ grueso/agua$$

$$\frac{Peso\ cemento}{Peso\ cemento} : \frac{Peso\ A.fino\ humedo}{Peso\ cemento} : \frac{Peso\ A.grueso\ humedo}{Peso\ cemento} / \frac{Agua\ efectiva}{Peso\ cemento}$$

Donde:

$$Agregado\ grueso \begin{cases} Humedad = \%W_g \\ \%absorcion = \%a_g \end{cases}$$

$$Agregado\ fino \begin{cases} Humedad = \%W_f \\ \%absorcion = \%a_f \end{cases}$$

$$Peso\ A.grueso\ humedo\ (kg) = (Peso\ A.grueso\ seco) * (1 + \frac{\%W_g}{100})$$

$$Peso\ A.fino\ humedo\ (kg) = (Peso\ A.fino\ seco) * (1 + \frac{\%W_f}{100})$$

Agua efectiva:

$$Agua\ en\ agregado\ grueso = (Peso\ A.grueso\ seco) * \left(\frac{\%W_g - \%a_g}{100}\right) = X$$

$$Agua\ en\ agregado\ fino = (Peso\ A.fino\ seco) * \left(\frac{\%W_f - \%a_f}{100}\right) = Y$$

$$Agua\ efectiva\ (lts) = Agua\ Neta - (X + Y)$$

2.1.2. Dosificación al volumen

Este método de dosificación es conocido como el más antiguo, fácil y cómodo, en todos los casos donde se presente falta de recursos para poder medir con exactitud los pesos del agregado y se necesite hacer el concreto de forma manual, este es utilizado para obras de menor tamaño ya que implica más costo y tiempo. Este método nos permite calcular las proporciones necesarias de cemento, agregados, agua de una manera rápida para poder realizar la mezcla de materiales.

En la siguiente tabla se muestra una forma fácil de generar la mezcla para un metro cubico de hormigón:

Dosificación o riqueza de cemento por metro cúbico de hormigón (kg/m³)	Proporciones			Litros			Material sólido necesario para 1 m³ de hormigón: 1450 ℓ Agua aproximada por m³, según cono: 150-250 ℓ Riqueza de cemento por m³, según calidad: 150-450 kg Peso aproximado de 1 m³ de hormigón: 2200-2500 kg Peso 1 saco de cemento: 50 kg Volumen de 1 saco de cemento: 33 litros Peso de 1 litro de cemento en saco: 1,5 kg
	Cemento	Arena	Grava	Cemento	Arena	Grava	Usos y empleos preferentes del hormigón
100	1	6	12	75	450	900	Rellenos. Hormigón de limpieza o pobre.
150	1	4	8	110	440	880	Zanjas. Cimientos. Grandes espesores.
200	1	3	6	145	435	870	Muros de contención. Pozos de cimentación. Soleras.
250	1	2,5	5	170	425	850	Pilares, soportes y prefabricados corrientes. Pavimentos.
300	1	2	4	207	415	830	Hormigones armados. Zapatas. Muros especiales.
350	1	2	3	240	480	720	Hormigones para estructuras. Pilares. Vigas.
400	1	1,5	3	263	395	790	Forjados delgados. Piezas a fatiga. Viguetas.
450	1	1,5	2,5	290	435	725	Prefabricados especiales. Pretensados. Postensados.
500	1	1	2	360	360	730	Trabajos y obras muy especiales de gran control.

En el caso que se requiera hacer cálculos, las proporciones se pueden obtener:

$$Cemento : Agregado\ fino : Agregado\ grueso/agua\ (\frac{lts}{bls})$$

$$\frac{Vol.cemento}{Vol.cemento} : \frac{Vol.\ A.fino}{Vol.cemento} : \frac{\frac{Vol.A.grueso}{Vol.cemento}}{Agua\ (\frac{lts}{Bls})}$$

Donde:

$$Cemento: Vol.cemento(m3) = \frac{Peso\ cemento\ (kg)}{P.U.cemento\ (\frac{kg}{m3})}$$

$$Agregado\ fino: Vol.A.fino\ (m3) = \frac{Peso\ A.fino\ humedo\ (kg)}{P.U.A.fino\ humedo(\frac{kg}{m3})}$$

$$Agregado\ grueso: Vol. A. grueso = \frac{Peso\ A. grueso\ humedo\ (kg)}{P.U.A. grueso\ humedo\ (\frac{kg}{m3})}$$

$$Agua\ \left(\frac{Lts}{Bls}\right) = \frac{Cantidad\ de\ agua\ por\ m3}{\frac{Peso\ cemento\ por\ m3}{Peso\ cemento\ por\ bolsa}}$$

2.1.3. Dosificación al peso con aditivo

Este método de dosificación es parecido al método al peso, pero en este, se utilizó un aditivo plastificante en el que hay reducir el agua en un 16% para realizar la pasta cementante.

2.2. Ensayos Destructivos

Los métodos destructivos de ensayo del hormigón son aquellos que producen daños o roturas a la muestra en análisis y averiguan como se va a comportar el material sometidos a diferentes solicitaciones físicas como por ejemplo los esfuerzos de compresión y tracción. Es decir, que analizarán la capacidad de estos a esfuerzos físicos (Laínez, Anastacio, & Arias, 2016).

Los ensayos destructivos son aquellos, en los cuales el material que va a ser sometido a estos no podrá ser utilizados nuevamente, es decir, que este tipo de ensayos suelen encargarse de llevar al límite las propiedades físicas del material o en muchos casos sobrepasarlos hasta llegar a la falla, identificando el comportamiento del material en situaciones extremas (Laínez et al., 2016).

Los ensayos destructivos más conocidos son:

- Compresión simple
- Resistencia a tracción
- Ensayo de corte
- Dureza
- Flexión
- Termofluencia

- Desgaste

En este trabajo se abordará, en el siguiente subcapítulo, el ensayo de compresión simple únicamente, ya que fue el seleccionado como base para la investigación.

2.2.1. Compresión Simple

El hormigón puede presentar una gran variedad de propiedades mecánicas y de duración buscando cumplir con las diferentes estructuras para los que fueron diseñados. La resistencia a la compresión del hormigón es la más utilizada en la industria de la construcción para diseñar las diferentes estructuras (American Society for Standard Testing and Materials (ASTM), 2015).

Figura 1. Maquina Universal

Fuente: Elaboración Propia

La resistencia a la compresión en cilindros se calcula a partir de la siguiente expresión que nos presenta la norma ASTM C39:

$$\sigma = \frac{P}{A}$$

Donde:

- P: Carga máxima aplicada (Kg)
- A: Área Transversal a la Fuerza (cm2)

Los requerimientos que nos da la norma ASTM C39 para la resistencia pueden variar entre 175 y 285 kg/cm2 para un concreto de uso residencial y para estructuras más comerciales se especifica que sean resistencias superiores a 715 kg/cm2 (American Society for Standard Testing and Materials (ASTM), 2015).

Según Laínez et al. (2016) los resultados de la compresión simple de cilindros normalmente son utilizados para:

- Determinar que la mezcla de hormigón cumpla con la resistencia para la que fue diseñada.
- Para fines de control de calidad, aceptación del hormigón, estimar la resistencia de este para programar la construcción de elementos, para evaluar las condiciones de curado y para fines investigativos como en nuestro caso que es correlacionar esta con los resultados del esclerómetro y ultrasonido.
- Marcar el tipo de falla de la muestra de hormigón.
- El registro histórico de resistencias se guardará para futuras construcciones o investigaciones.

2.2.2. Procedimiento de Ensayo

El procedimiento presentado está basado en la norma ASTM C39:

1. Los ensayos de compresión de muestras curadas con humedad se deberán realizar lo antes posible después de sacarlas del sitio de almacenamiento.
2. Las muestras se mantendrán húmedas por cualquier método conveniente, se recomienda una toalla húmeda, durante el período comprendido entre la salida de la cámara de humedad y el ensayo. Se someterán las muestras en estado húmedo.
3. En el caso que se necesite diferentes condiciones se las puede hacer, en nuestro caso a los 7 días se trabajó la compresión simple en estado húmedo y a los 28 días en estado seco para poder cumplir con las condiciones de los otros ensayos.

4. Preparación de la muestra:
   - Se debe anotar la fecha en la que se realizara el ensayo y la edad de la muestra
   - Tomar dos medidas del diámetro del cilindro para poder hacer un promedio de estas posteriormente, esta servirá para el cálculo del área.

Figura 2. Medición de Diámetros

Fuente: Elaboración Propia

   - Se debe tomar tres medidas de la altura del cilindro para poder hacer un promedio de estas posteriormente, esta servirá para el cálculo del área.

Figura 3. Medición de Alturas

Fuente: Elaboración Propia

- Pesar la muestra.

Figura 4. Cilindros Medidos y Pesados

Fuente: Elaboración Propia

- Al culminar de tomar estos datos se debe llevar la muestra a la máquina.

5. Limpiar tanto el soporte superior como inferior antes de colocar el cilindro y luego colocar los soportes en el cilindro.

Figura 5. Colocación del Soporte Inferior y Superior

Fuente: Elaboración Propia

6. Colocar el cilindro centrado en la parte inferior del plato de la maquina con el centro de empuje el cual nos proporcionara la carga.

Figura 6. Centrar el Cilindro con el Centro de Empuje

Fuente: Elaboración Propia

7. Antes de poner la carga hay que verificar que el indicador de carga este en cero.

Figura 7. Indicador de Carga en Cero

Fuente: Elaboración Propia

8. Aplicar la carga a una velocidad constante normada de 0.05 a 0.25 Mpa/s.
9. Se debe aplicar la carga hasta que el indicador nos muestre que disminuye o hasta que exista la rotura de la muestra.

Figura 8. Rotura de Cilindros

Fuente: Elaboración Propia

10. Anotar la carga de cada una de las muestras ensayadas respectivamente.

Figura 9. Resultado

Fuente: Elaboración Propia

11. Desechar las muestras ensayadas.

Figura 10. Muestras Ensayadas

Fuente: Elaboración Propia

2.2.3. Cálculos

1. Calcular la resistencia a la compresión con la siguiente expresión:

$$\sigma = \frac{P}{A}$$

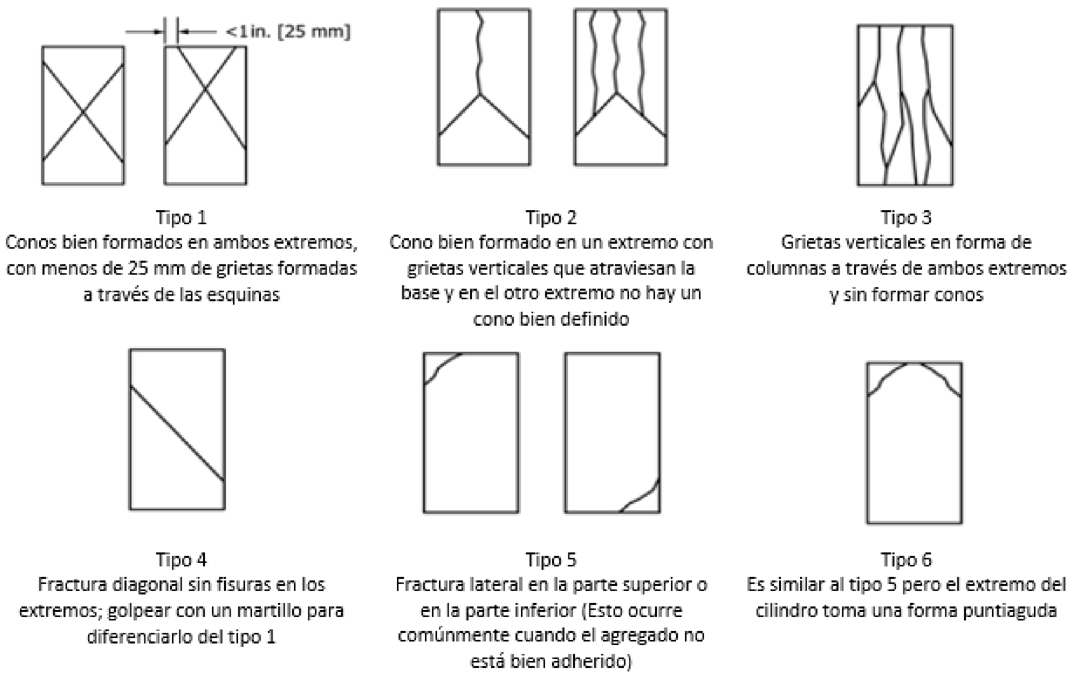
(American Society for Standard Testing and Materials (ASTM), 2015)

Donde:

- P: Carga máxima aplicada (Kg)
- A: Área Transversal a la Fuerza (cm2)

2. Verificar el tipo de falla según la siguiente imagen:

Figura 11. Tipos de Falla



Fuente: American Society for Standard Testing and Materials (ASTM), 2015

3. Se debe dividir el valor de longitud del cilindro para el diámetro medido de la muestra, si este resultado da entre 1.75 o menor a este, se debe aplicar un factor el cual busca corregir el valor de la resistencia del hormigón, los fatores los podemos observar en la tabla 1 presentada a continuación:

Tabla 1. Factor de Corrección por Longitud/Diámetro

L/D	1.75	1.50	1.25	1.00
Factor	0.98	0.96	0.93	0.87

Fuente: American Society for Standard Testing and Materials (ASTM), 2015

Utilizar el método de interpolación para determinar los factores de corrección para valores diferentes a los mostrados en la tabla 1, esto se explica para valores intermedios, en el caso de que la relación entre la longitud y el diámetro sea mayor a 1.75 el factor de corrección tomara el valor de 1.

2.3. Ensayos no destructivos del hormigón

2.3.1. Importancia y necesidad de uso de los ensayos no destructivos en el hormigón

A menudo es necesario probar las estructuras de hormigón después de que este se haya endurecido para determinar si la estructura es adecuada para lo que fue diseñada, lo ideal es que estas pruebas se realicen sin dañar el hormigón (International Atomic Energy Agency, 2002).

Los ensayos disponibles van desde los totalmente no destructivos, en los que no hay daños en el hormigón, pasando por aquellos en los que la superficie de hormigón está ligeramente dañada, hasta los parcialmente destructivos, como los ensayos de núcleo y los de tracción y extracción, en los que la superficie debe ser reparada después del ensayo (International Atomic Energy Agency, 2002).

La gama de propiedades que pueden evaluarse mediante ensayos no destructivos y ensayos parcialmente destructivos es bastante amplia e incluye parámetros fundamentales como la densidad, el módulo de elasticidad y la resistencia, así como la dureza de la superficie y la absorción de esta, y la ubicación, el tamaño y la distancia de la armadura a la superficie (International Atomic Energy Agency, 2002).

En algunos casos también es posible comprobar la calidad de la mano de obra y la integridad estructural detectando vacíos, grietas y desprendimientos de la superficie (International Atomic Energy Agency, 2002).

Los ensayos no destructivos se pueden aplicar tanto a estructuras antiguas como nuevas. En el caso de las estructuras nuevas, su principal objetivo es el control de calidad o para aclarar las dudas que puedan existir sobre la calidad de los materiales o de la construcción (International Atomic Energy Agency, 2002).

Las pruebas para estructuras antiguas suelen estar relacionadas con su evaluación. En cualquier caso, si se utilizan únicamente ensayos destructivos, por ejemplo, extrayendo núcleos para ensayarlos a compresión, el costo de la extracción y posteriores ensayos solo permitirá realizar un número relativamente pequeño de ensayos en una estructura de gran tamaño, lo cual puede dar error. Los ensayos no destructivos pueden utilizarse como un paso previo a la extracción de núcleos (International Atomic Energy Agency, 2002).

De acuerdo con International Atomic Energy Agency (2002) los ensayos no destructivos pueden ser útiles en las siguientes situaciones:

- Controlar la calidad de piezas prefabricadas o de la construcción in situ.
- Eliminar la incertidumbre sobre la aceptabilidad del material suministrado debido al incumplimiento de las especificaciones.
- Confirmar o negar dudas sobre la mano de obra en dosificaciones, mezcla, colocación, compactación o curado del hormigón.
- Supervisar la resistencia en relación con el desencofrado.
- Localizar y determinar de grietas, huecos y defectos similares dentro de una estructura de hormigón.
- Determinar la homogeneidad del hormigón, antes de la extracción de núcleos, pruebas de carga u otras pruebas más costosas y destructivas.
- Determinar la posición, cantidad o condición de la armadura.
- Aumentar el nivel de confianza para un número menor de ensayos destructivos.
- Determinar el sitio de muestreo representativo de la calidad que debe evaluarse.
- Confirmar o localizar el deterioro del hormigón debido a factores como la sobrecarga, la fatiga, el ataque o cambio químico externo o interno, el fuego, la explosión o los efectos del medio ambiente.
- Evaluar la durabilidad potencial del hormigón.
- Controlar los cambios a largo plazo en las propiedades del hormigón.
- Proporcionar la información necesaria para correlacionar resultados.

2.3.2. Ensayos no destructivos aplicados a estructuras de hormigón

A continuación, se mostrarán los métodos y aplicaciones típicas que se utilizan para realizar ensayos no destructivos en el hormigón acorde al International Atomic Energy Agency (2002):

- Inspección Visual: Es un paso esencial antes de realizar cualquier ensayo no destructivo.
- Método de potencial eléctrico de la armadura central: Es usado para detectar la corrosión de las barras de refuezo en el hormigón.
- Martillo Schmidt o esclerómetro: Empleado para evaluar la dureza superficial del concreto y la resistencia a la compresión.
- Prueba de profundidad de carbonatación: Se utiliza para determinar si la humedad ha llegado hasta las barras de acero y por medio de esto saber si existe corrosión.
- Ensayo de permeabilidad: Es utilizado para medir el flujo de agua a través del hormigón.
- Resistencia a la penetración o pistola Windsor: Sirve para medir la resistencia de la superficie y de las capas adyacentes a la superficie del hormigón.
- Ensayo de medición de recubrimiento: Es empleado para medir la distancia de las barras de acero debajo del recubrimiento de hormigón y también es utilizado para medir el diámetro de las barras.
- Ensayos de radiografía: Es utilizado para detectar vacíos en el hormigón y la posición de los conductos de tensado.
- Ensayo de velocidad de pulso ultrasónico: Principalmente para medir la velocidad del sonido a través del hormigón y la resistencia a la compresión.
- Modelado tomográfico: Es el que utiliza los datos de transmisión ultrasónica en dos o más direcciones para detectar grietas en el hormigón.
- Ensayo de eco impacto: Para detectar huecos, desprendimientos y otras anomalías en el hormigón.

- Ensayo de radar de penetración en el suelo o de radar de impulsos: Es utilizado para detectar la posición de las barras de refuerzo o conductos de tensión.
- Termografía Infrarroja: Es utilizado para detectar vacíos y otras anomalías en el hormigón o también para detectar puntos de entrada de agua en las paredes de la edificación.

En nuestro caso vamos a hablar de dos de estos ensayos no destructivos del hormigón presentados a continuación.

2.4. Ultrasonido

Este aparato es utilizado para medir el tiempo de transmisión de una onda ultrasónica dentro del hormigón, entre un transmisor y un receptor acoplados a este. La velocidad de propagación obtenida tiene relación con los parámetros elásticos del material e indirectamente con las propiedades de resistencia, es por esto por lo que se hace una correlación para obtener un factor de comparación entre la resistencia y la velocidad de propagación de onda (Kamekura Seiki Co., 2015).

Figura 12. Ultrasonido Elsonic ESI/P-10 y Ultrasonido Tico

Fuente: Elaboración Propia

2.4.1. Principio de Operación

Los impulsos de las ondas de tensión longitudinales son generados por un transmisor electroacústico que se mantiene en contacto con la superficie del hormigón, después de atravesarlo, los impulsos son recibidos y convertidos en energía eléctrica por un receptor situado a una distancia L del transmisor (Kamekura Seiki Co., 2015).

2.4.2. Medida de la velocidad de propagación de onda:

La velocidad de propagación de onda se traslada a través de un material sólido y este depende de la densidad y las características elásticas del material, en varios casos la calidad de los materiales se relaciona con la resistencia elástica, el ultrasonido en mucho de los casos medirá la calidad de los materiales así como sus características elásticas (El & Material, 2010).

2.4.2.1. Velocidad de propagación de onda en solidos elásticos:

La siguiente expresión nos muestra como calcular la velocidad de propagación de onda en solidos elásticos:

$$V = \sqrt{\frac{E}{P} * \frac{(1-\mu)}{(1+\mu) * (1+2*\mu)}}$$

(ASTM C597, 2016)

Donde:

E: Modulo de elasticidad dinámico

P: Densidad

μ: Razón de Poisson

Esta ecuación presentada se usa para medir la velocidad de propagación de onda en un sólido elástico con cualquier dimensión o tamaño (El & Material, 2010).

Dicha velocidad es inversamente proporcional a la frecuencia de esta, también estas dependerán de las características de la muestra ensayada teniendo como resultado la condición del material y su calidad (El & Material, 2010).

2.4.2.2. Métodos de prueba:

Se necesita un resultado lo más exacto posible para poder medir o evaluar la calidad del hormigón por medio de la velocidad de propagación de onda, el aparato que mida dicho resultado debe generar pulsos convenientes y que mida exactamente el tiempo de transmisión de la onda del elemento a ser ensayado (El & Material, 2010).

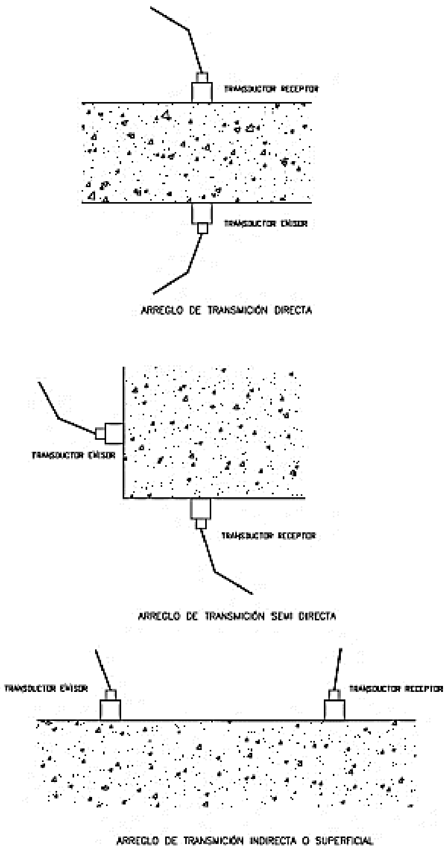
Es de gran importancia que se mida la longitud del elemento donde se va a transmitir la onda ya que esta nos va a permitir junto con el tiempo de transmisión medir la velocidad de propagación de onda en la muestra ensayada (El & Material, 2010).

La longitud y el tiempo de transmisión de onda se debe medir con una exactitud de +/- 1 % (El & Material, 2010).

2.4.2.3. Posiciones de los transductores:

En la siguiente figura se muestra 3 formas de colocar los transductores para poder medir el tiempo de transmisión de onda por el método directo:

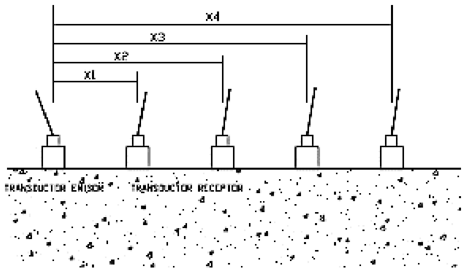
Figura 13. Arreglos para la colocación de los transductores



Fuente: El & Material, 2010

Basados en El & Material (2010) el método indirecto es menos exacto ya que este mediría solo la velocidad de transmisión de onda en la superficie de la muestra, sin llegar a el interior de esta y dándonos un mayor error en esta, en la siguiente figura se muestra la forma como se hace esta medición:

Figura 14. Determinación de la Velocidad del Pulso por el Método Indirecto



Fuente: El & Material, 2010

Factores que afectan a la medición de la velocidad de transmisión de onda:

2.4.2.4. Longitud de transmisión

La longitud de transmisión de onda afecta al resultado dependiendo del tamaño máximo del agregado, este no deberá ser menos de 4 pulgadas cuando se utiliza un tamaño máximo de agregado de 0.75 pulgadas o no menos a 6 pulgadas cuando el tamaño máximo del agregado es de 1.5 pulgadas (El & Material, 2010).

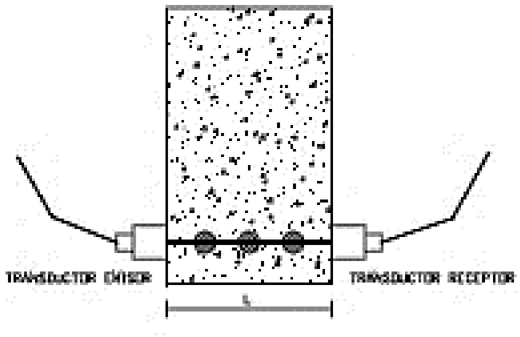
2.4.2.5. Dimensiones de la muestra

La velocidad de propagación de onda se verá afectada si es que la dimensión perpendicular a la medida es menor a la longitud de la onda (El & Material, 2010).

2.4.2.6. Presencia de acero de refuerzo

Cuando existe acero de refuerzo la velocidad de propagación de onda se puede ver afectada ya que este puede hacer interferencia en el camino de esta haciendo que se demore más el paso de dicha onda (El & Material, 2010).

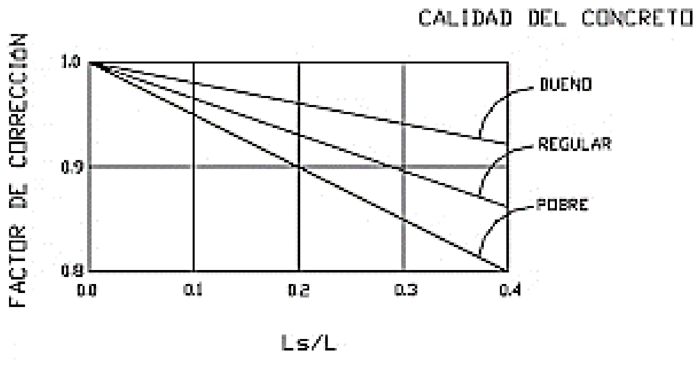
Figura 15. Influencia de las barras de acero en la velocidad de Pulsos de Ultrasonido



Fuente: El & Material, 2010

Cuando exista acero de refuerzo se deberá aplicar el siguiente grafico para poder determinar el factor de corrección correspondiente:

Figura 16. Influencia de las barras de acero en la velocidad de pulsos de ultrasonido



Fuente: El & Material, 2010

Este dependerá de la calidad del hormigón y de la relación entre la longitud de transmisión de onda y la longitud del acero de refuerzo a lo largo de la superficie de medición (El & Material, 2010).

2.4.2.7. Contenido de agua

El contenido de agua tiene una influencia baja pero importante en el momento de calcular la velocidad de transmisión de onda (El & Material, 2010).

En el concreto saturado puede aumentarse la velocidad de propagación en un 2% más q en el hormigón en estado seco que tenga las mismas características, este valor baja cuando se trata de hormigones de alta resistencia (El & Material, 2010).

2.4.3. Procedimiento de ensayo

Proceso de medición de la velocidad de propagación de onda en el equipo Elsonic ESI/P-10 según el manual de usuario y la norma ASTM C 597:

La medición de la distancia se debe hacer con un flexómetro y la del tiempo con el equipo Elsonic (ASTM C597, 2016; Kamekura Seiki Co., 2015).

2.4.3.1. Principio de medición de la velocidad de propagación de onda

Basado en Kamekura Seiki Co. (2015) los principios de medición de la velocidad de propagación de onda son:

- Elsonic meter genera pulsos de alto voltaje entre 1 Kv o 500 V y los envía al sensor de transmisión.
- Las ondas ultrasónicas se generan por el efecto piezoeléctrico sobre el elemento en el sensor de transmisión.
- Las ondas ultrasónicas se propagan en el concreto y se transmiten al sensor del receptor en el lado opuesto.
- El sensor del receptor envía el voltaje generado por el efecto piezoeléctrico, al equipo.
- Elsonic meter mide el tiempo entre la transmisión y la entrada de la señal de recepción con una resolución de 0.1 microsegundos y muestra el resultado en la pantalla digital.

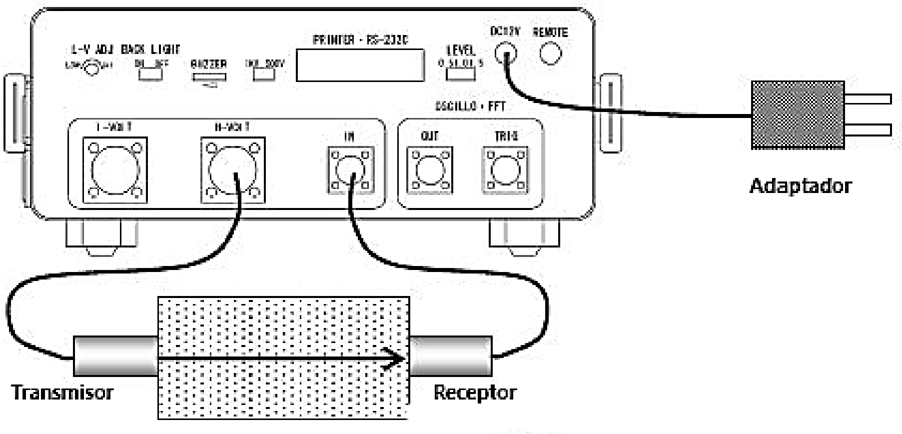
2.4.3.2. Otros:

Elsonic permitirá evaluar el nivel de estabilidad por medio del parpadeo de las lámparas FAR (roja) y NEAR (verde) y a su vez la variación de los valores en la pantalla digital.

2.4.3.3. Proceso de medición:

1. Conectar el adaptador, el transmisor y el receptor como se muestra en la figura 11.

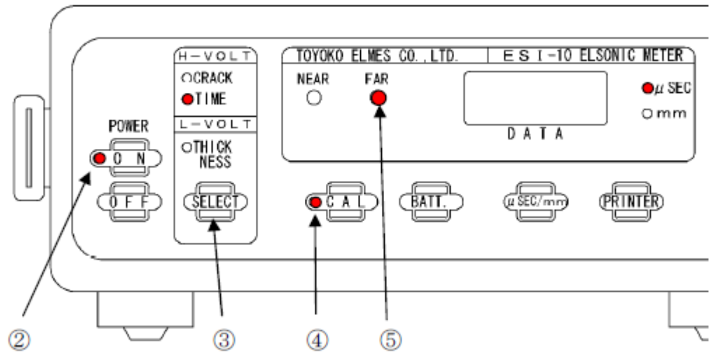
Figura 17. Ultrasonido Elsonic ESI/P-10



Fuente: Manual de Usuario Elsonic ESI/P-10 (Kamekura Seiki Co., 2015)

2. Presionar la tecla (ON) para prender la máquina.
3. Presione la tecla (Select) dos veces para poder medir el tiempo de onda.

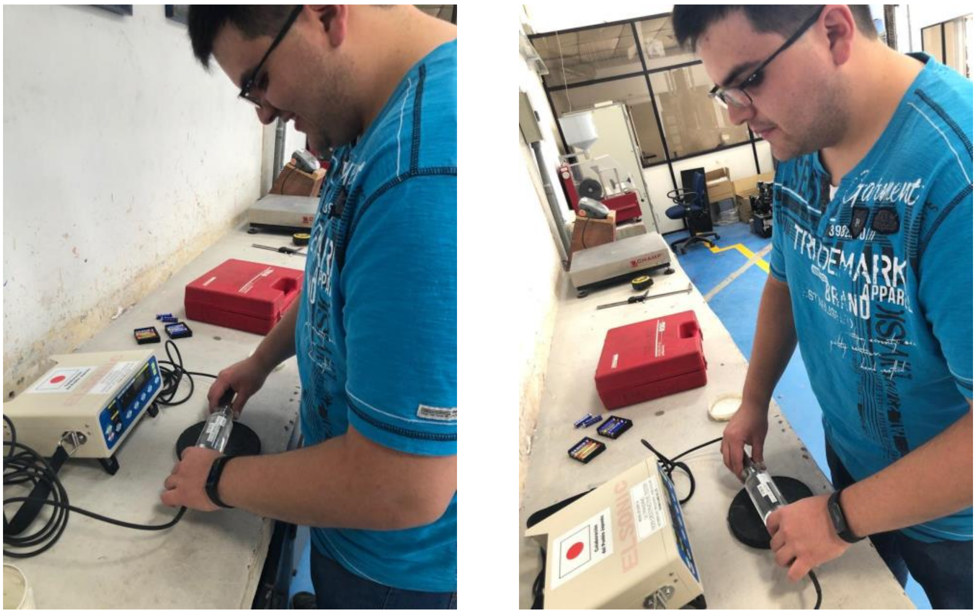
Figura 18.Pasos para medir el tiempo de onda



Fuente: Manual de Usuario Elsonic ESI/P-10 (Kamekura Seiki Co., 2015)

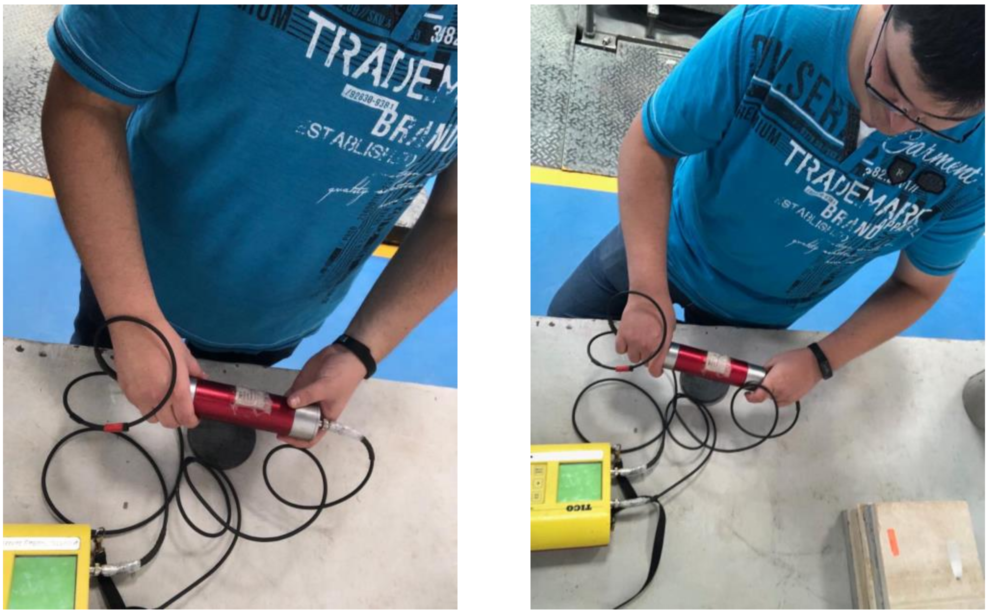
2.4.3.4. Calibración del equipo:

Figura 19. Calibración del Equipo Elsonic ESI/P-10



Fuente: Elaboración Propia

Figura 20. Calibración del Equipo Ultrasonido Tico



Fuente: Elaboración Propia

- Presionar la tecla (CAL) hasta que se encienda la luz.
- En el modo de medición de tiempo, se debe poner los sensores cara a cara de tal manera que exista un contacto ligero entre sí.

- Acercar el cilindro de calibración y agregar vaselina en ambas caras planas, en este cilindro está escrito el tiempo en microsegundos para calibrar el equipo en este caso es de 37 microsegundos.
- Colocar el transmisor y el receptor en las caras planas opuestas cuando en la pantalla digital se observe el valor de 37 microsegundos presionar (CAL) y este valor quedara guardado.
- Presionar nuevamente la tecla (CAL) y medir nuevamente el cilindro de prueba, pero en esta ocasión deberá aparecer 000.0 esto indicará que la calibración está completa.
- Repetir el proceso cada vez que se encienda el equipo.

2.4.3.5. Medición del tiempo de propagación de onda:

- Limpiar el área donde se va a hacer la medición y aplicar el medio de contacto, este puede ser vaselina, aceite, etc.

Figura 21. Aplicación del Medio de Contacto

Fuente: Elaboración Propia

- Colocar en la superficie del concreto el transmisor y el receptor de tal manera que estos se opongan entre sí.

Figura 22. Medición de la Velocidad de Propagación de Onda

Fuente: Elaboración Propia

- Cuando la luz roja (FAR) se encienda y el valor de la pantalla digital se hayan estabilizado procedemos a anotar el valor indicado.
- Para obtener una mejor medición de la velocidad de propagación de onda se recomienda hacer diferentes mediciones y luego calcular la media de estos.

2.4.4. Cálculos:

Para el cálculo de la velocidad de propagación de onda en el concreto se debe usar la siguiente ecuación extraída de la norma ASTM C 597:

$$V = \frac{L}{t}$$

Donde:

V: Velocidad de propagación de onda (m/s)

L: Distancia entre transductor y receptor (m)

t: Tiempo de transmisión de onda en el concreto (s)

Normalmente la velocidad de propagación de onda en el hormigón es de 4000 m/s±10%, y también se puede determinar la calidad del hormigón según su velocidad mediante la siguiente tabla:

Clasificación de la calidad del hormigón por medio de la velocidad de onda según Leslie y Cheesman:

Tabla 2. Clasificación de Calidad del Hormigón por Medio de la Velocidad de Propagación de Onda según Leslie y Cheesman

Velocidad de Propagación (m/s)	Condición del Hormigón
Más de 4570	Excelente
3050-4570	Buena
3050-3650	Regular
2130-3050	Pobre
Menor de 2130	Muy Pobre

Fuente: Tecnología del Hormigón UCV

Evaluación de calidad mediante la velocidad de propagación de onda según Agraval y otros:

Tabla 3. Calidad del Hormigón Mediante la Velocidad de Propagación de Onda Según Agraval y otros

Velocidad de Propagación (m/s)	Condición del Hormigón
Más de 3000	Buena
2500-3000	Regular
Menor de 2130	Pobre

Fuente: Tecnología del Hormigón UCV

2.5. Esclerómetro (Concrete Test Hammer R-7500)

Se conoce que la determinación del índice esclerómetro en los hormigones es simplemente un indicativo de su resistencia mecánica, con una gran variabilidad de resultados, es uno de los métodos no destructivos comúnmente utilizados en la reconstrucción de estructuras. Se podría decir que su uso es común ya que este tiene un bajo costo, es de fácil traslado y por su facilidad de uso. A pesar de que existen muchas curvas que correlacionan a el índice esclerómetro con la compresión simple o resistencia a la compresión, este se ve afectado por varios factores que podrían afectar a sus resultados (Gómez Cortés, 1987).

El esclerómetro más conocido en el mercado es el inventado por el ingeniero suizo Ernst Schmidt en 1948, a partir de este se han creado 4 tipos de martillos que los mencionare a continuación:

1. El estándar para las construcciones en general.
2. Una versión pequeña para que se pueda usar en superficies muy sensibles al impacto realizado por este.
3. Un tipo de esclerómetro el cual es utilizado para grandes masas y secciones gruesas.
4. Un martillo tipo péndulo que es utilizado en materiales con bajas resistencias.

También existen aparatos digitales que guardan sus datos en una memoria integrada al dispositivo y algunos de estos nos ayudan sacando el valor promedio de los índices medidos con este y se está pensando desarrollar un esclerómetro que funcionaria bajo el agua (Gómez Cortés, 1987).

Figura 23. Concrete Test Hammer R-7500

Fuente: Elaboración Propia

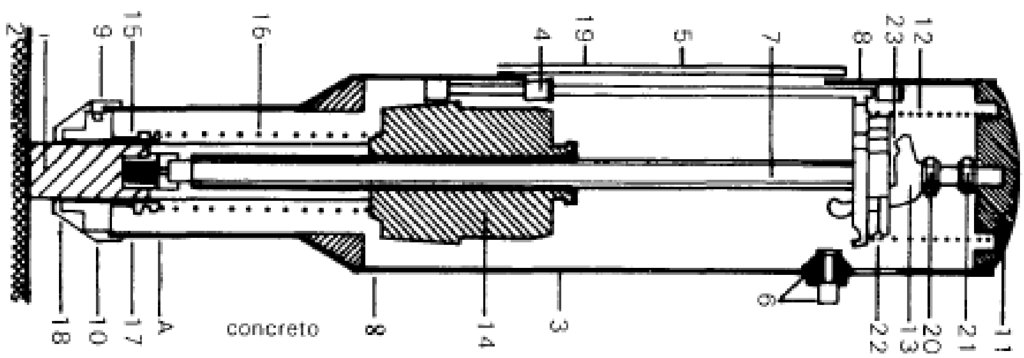
El esclerómetro es utilizado para medir la dureza de la superficie de cualquier masa de hormigón. La resistencia a la compresión aproximada del hormigón es mostrada por los resultados que nos entrega la máquina. Esta prueba es considerada no destructiva por lo tanto es un método simple, rápido y conveniente al ser utilizado.

2.5.1. Principio de Operación

El esclerómetro se basa en la relación proporcional entre el número de rebote de un martillo de acero y la resistencia a la compresión del hormigón. Este número de rebote se obtiene a partir de que el martillo de acero de carga elástica se libere golpeando un embolo de acero en contacto con la superficie del concreto. Después se mide en una escala lineal la distancia del martillo de rebote de acero desde el embolo que está unida al marco de la máquina. Dicha escala esta calibrada de tal manera para expresar la distancia de rebote como un porcentaje de la distancia total que recorre el martillo antes del impacto. Este valor de distancia de rebote “R” se llama número de rebote el cual da un valor de la dureza de la superficie del hormigón (Kamekura Seiki Co., 2016).

2.5.1.1. Partes del esclerómetro:

Figura 24. Partes del Esclerómetro



Fuente: Gómez Cortés, 1987

1. Embolo de impacto
2. Superficie de cemento
3. Alojamiento
4. Guía
5. Escala
6. Reten
7. Guía del martillo
8. Disco
9. Tapadera
10. Aro en dos partes
11. Cubierta posterior
12. Muelle de compresión

13. Trinquete
14. Masa del martillo
15. Aro de reten
16. Muelle de impacto
17. Guía del aparato
18. Arandela
19. Ventanilla
20. Tornillo de desplazamiento
21. Contratuerca
22. Pasador
23. Muelle de trinquete

2.5.1.2. Factores que afectan la lectura del índice de rebote:

De acuerdo con Gómez Cortés (1987) se han identificado varios factores que afectan los resultados del índice de rebote, entre los más importantes se encuentran:

1. Tipo de cemento.
2. Contenido, tipo y tamaño máximo del agregado.
3. Textura y forma de la superficie.
4. Posición del aparato.
5. Carbonatación superficial del hormigón.
6. Diferentes capas del hormigón.
7. Condiciones de humedad en la superficie.
8. Destreza del operador.

A continuación, hablaremos de cada uno de estos factores:

2.5.1.3. Tipo de cemento:

El cemento con el que está hecho el cilindro de hormigón nos da una dureza característica que dependerá totalmente del contenido de puzolana en el cemento y a la calidad de este, el índice esclerómetro se vería afectado ya que mide la dureza de la superficie (Gómez Cortés, 1987).

2.5.1.4. Contenido, tipo y tamaño máximo del agregado

Se ha observado que cuando existe mayor contenido de agregados por volumen de concreto, el índice esclerómetro tiene valores más altos, también se ve un aumento cuando existe tamaños máximos de los agregados pequeños que en los tamaños grandes (Gómez Cortés, 1987).

2.5.1.5. Forma y textura de la superficie:

La forma de la superficie y la textura que deja el molde del cilindro nos dan una variación sobre el índice esclerómetro, en superficies planas nos da un pequeño incremento a comparación de las superficies curvas (Gómez Cortés, 1987).

2.5.1.6. Posición del aparato:

Es claro que al depender de la masa el índice de rebote medido se verá afectado por la posición del dispositivo ya sea horizontal (0°), inclinado hacia arriba (90°) e inclinado hacia abajo (-90°). Debido a que la componente de la gravedad actuara a favor o no sobre el rebote de dicha masa. En el esclerómetro normalmente nos mandan una ilustración de curvar la cual nos muestra los ángulos y sus respectivos valores de resistencia para cada una de estas direcciones (Gómez Cortés, 1987).

2.5.1.7. Carbonatación superficial del hormigón:

Normalmente se presenta dicha carbonatación en hormigones que tienen una edad avanzada, esta afecta a la resistencia de su superficie mas no a la resistencia mecánica de la muestra a ensayarse (Gómez Cortés, 1987).

La carbonatación consiste en que el anhídrido carbónico que se introduce a través del aire a los poros del hormigón se combina con el hidróxido de calcio, que forman carbonato de calcio neutro y agua:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

(Gómez Cortés, 1987)

El efecto que esto hace es que el pH líquido que se presenta en los poros, de un valor de 12 a 13 se vea reducido gradualmente, si este valor de pH es menor a 9.5 el hormigón es conocido como “Hormigón Carbonatado”, que aparte de aumentar la dureza de la superficie, no alcance a cubrir al acero de la corrosión y se produzca este efecto (Gómez Cortés, 1987).

La carbonatación se presentará naturalmente de afuera hacia el interior y su velocidad de penetración dependerá de los siguientes factores:

- Humedad relativa del medio ambiente
- Contenido de CO2 del medio ambiente

- Porosidad y contenido de cemento del hormigón

Se ha observado que la profundidad de la capa de carbonatación para una edad de 30 años con condiciones favorables es de unos 3 mm y de 2 mm en 10 años para condiciones desfavorables en el hormigón (Gómez Cortés, 1987).

2.5.1.8. Capas diferentes de hormigón:

En el caso que existiera dos o más capas de hormigón, se crea una discontinuidad en la superficie de contacto afectando al índice esclerómetro, haciéndose más significativa si las capas presentan valores muy diferentes, cabe recalcar que cuando existe una capa de recubrimiento con mortero esta debe ser retirada para efectuar el ensayo (Gómez Cortés, 1987).

2.5.1.9. Condición de humedad:

La presencia de agua en la superficie de la muestra de hormigón desarrolla un efecto de amortiguador sobre el golpe que ejerce la masa. Mostrándonos que en las superficies húmedas exista una disminución en el índice esclerómetro que en las superficies secas (Gómez Cortés, 1987).

2.5.1.10. Destreza del operador:

Se ha comprobado que la destreza del operador al rato de ejerces la presión sobre el resorte de manera suave y gradual evita los impulsos de manera que este proceso también hace efecto sobre el valor del índice esclerómetro (Gómez Cortés, 1987).

En una investigación desarrollada en el laboratorio de ensayos de materiales de la Universidad Nacional de Colombia se presentó variaciones presentadas en la siguiente tabla. Todos fueron evaluados con los mismos puntos, en un bloque con dimensiones de 1.2x1.2x0.9 m en dos sitios diferentes y a los tercios medios de la altura (Gómez Cortés, 1987).

En la tabla de análisis presentada para un mismo punto existen diferencias hasta de ocho en los resultados del índice esclerómetro estos oscilan entre 1 y 8 de diferencia (Gómez Cortés, 1987).

Figura 25. Ejemplo de la Influencia del Operador

	Izquierda								Derecha							
	(A)		(B)		(C)		(D)		(A)		(B)		(C)		(D)	
	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R
Arriba	32	(1)	37	(8)	34	(3)	35	(6)	32	(3)	35	(8)	34	(4)	33	(4)
Centro	31	(1)	38	(8)	35	(5)	39	(8)	36	(7)	35	(7)	35	(5)	37	(10)
Abajo	32	(3)	36	(4)	36	(5)	38	(6)	36	(9)	41	(6)	37	6)	39	(11)

I: Indice esclerométrico determinado (promedio de seis lecturas).
R: Recorrido de lecturas (mayor valor - menor valor)
(A): Laboratorista con experiencia
(B): Laboratorista sin experiencia
(C): Ingeniero con experiencia
(D): Estudiante de tesis, sin experiencia

Fuente: Gómez Cortés, 1987

2.5.2. Especificaciones básicas del modelo Concrete Test Hammer R-7500

Figura 26. Especificaciones Básicas

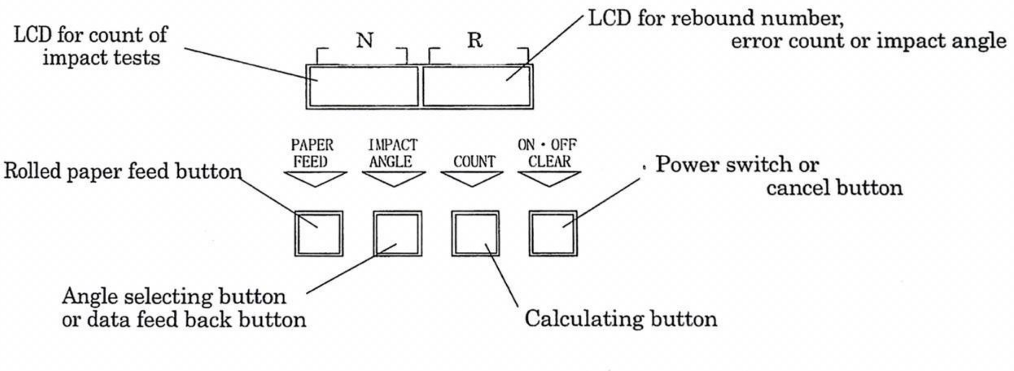
Fuente: Elaboración Propia

- Peso del Martillo: 375 g
- Distancia de recorrido del martillo: 75 mm
- Energía de Impacto: 2.207 Nm
- Valor standard del yunque de calibración: 80±2
- Rango de Medida: 10-70 N/mm²
- Temperatura: 0-40 °C
- Baterías: LR-6 (Alcalina) 1.5V 4 baterías AA son necesarias (Kamekura Seiki Co., 2016)

2.5.3. Proceso de Uso del Concrete Test Hammer R-7500

2.5.3.1. Ilustración de la pantalla y los botones de operación del sistema

Figura 27. Ilustración de la pantalla y botones de operación del sistema



Fuente: Manual de Usuario Concrete Test Hammer R-7500

2.5.3.2. Manejo del equipo

Siguiendo lo descrito en Kamekura Seiki Co. (2016) el procedimiento para el manejo del esclerómetro es:

- Para el uso de la impresora mover el interruptor al lado que dice "PRINT" y luego presionar el botón de encendido "ON/OFF".
- Luego seleccionar el ángulo de impacto (-90°,0°,90°) presionando el botón "Impact Angle". En el caso de elegir 0° se puede omitir este paso. Tomar en cuenta que al rato de imprimir los resultados se muestra el ángulo de ensayo al final.
- Apoye la cabeza del martillo en ángulos rectos contra la superficie del concreto a probar. Presione el martillo de forma continua y justo antes que el embolo desaparezca por completo, se suelta la masa del martillo y se produce el impacto.
- Después del impacto, remueva el martillo y el número de impactos como el número de rebote será mostrada en la pantalla. Al mismo tiempo estos resultados serán impresos automáticamente en el papel.
- Para nuevos ensayos, repita los pasos 4.4. y 4.5.
- Cuando se cumpla el número de impactos deseado para el ensayo, presione el botón "COUNT" y se imprimirá el valor promedio. El número de impactos que se puede realizar es de 99 impactos máximo.

Si se muestra algún valor con el símbolo “E”, repita el impacto en el área cercana para obtener datos consistentes y poder corregir el error. El símbolo “E” y el numero indica que existe un error en los datos que superan el ±20% del valor promedio.

- Si es que se quiere hacer otra medición se tiene que aplastar el botón “ON/OFF” para que se reinicie la memoria y comience nuevamente.
- Aplaste el botón “PAPER FEED” hasta que llegue el final de los datos y después cortarlo.

2.5.4. Procedimiento de ensayo (ASTM C805-18)

2.5.4.1. Selección de área de prueba

- La prueba debe realizarse en áreas planas y lisas de las estructuras de hormigón de acuerdo con su forma. Se debe evitar realizar en áreas porosas o rugosas.
- Seleccione superficies lisas, limpias y secas si es posible, probar en la superficie vertical del elemento.
- Los elementos de prueba deben tener más de 10 cm de espesor.

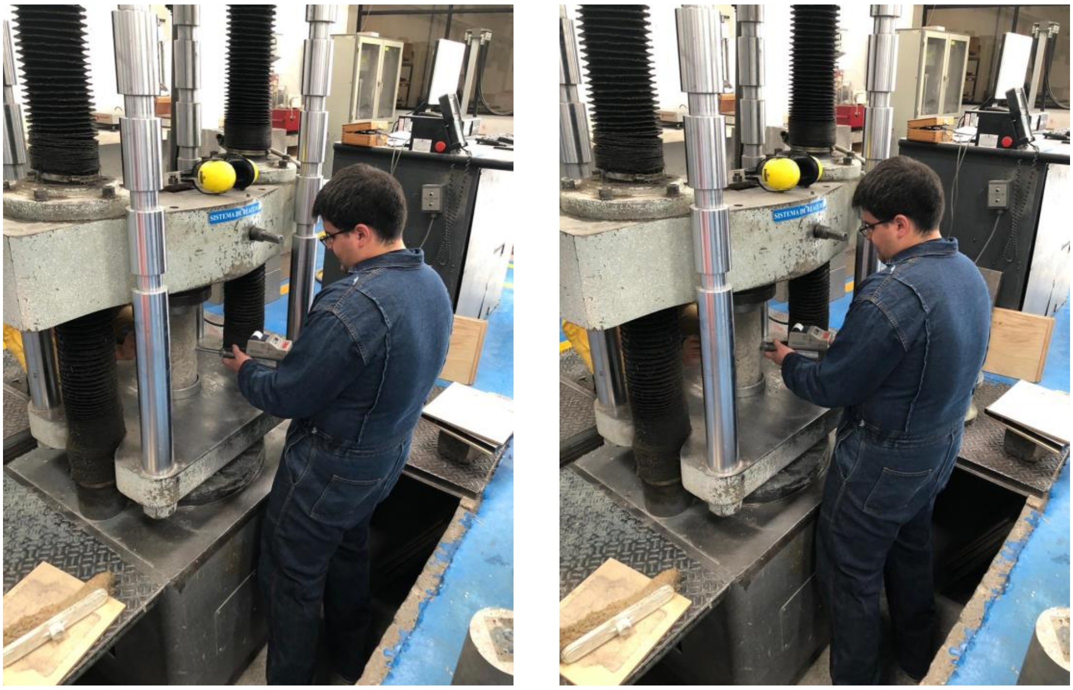
2.5.4.2. Preparación de la superficie

- El área de prueba debe tener el tamaño necesario para poder cumplir con el número de impactos que necesitemos, según la norma ASTM-C805 se necesitan por lo menos 10 impactos.
- En superficies irregulares se debe utilizar una amoladora eléctrica para mejorar dichas irregularidades.
- Cualquier capa de recubrimiento que cubra el hormigón deberá ser removido.
- Los hormigones de más de 6 meses de fundidos pueden requerir ser pulidos hasta una profundidad de 5 a 6 mm.
- Las superficies que son ligeramente desiguales se pueden mejorar con la piedra rugosa que viene junto a la máquina.

- Se recomienda secar las superficies húmedas durante 24 horas antes de realizar la prueba.

2.5.4.3. Proceso de ensayo

Figura 28. Prueba de Esclerómetro

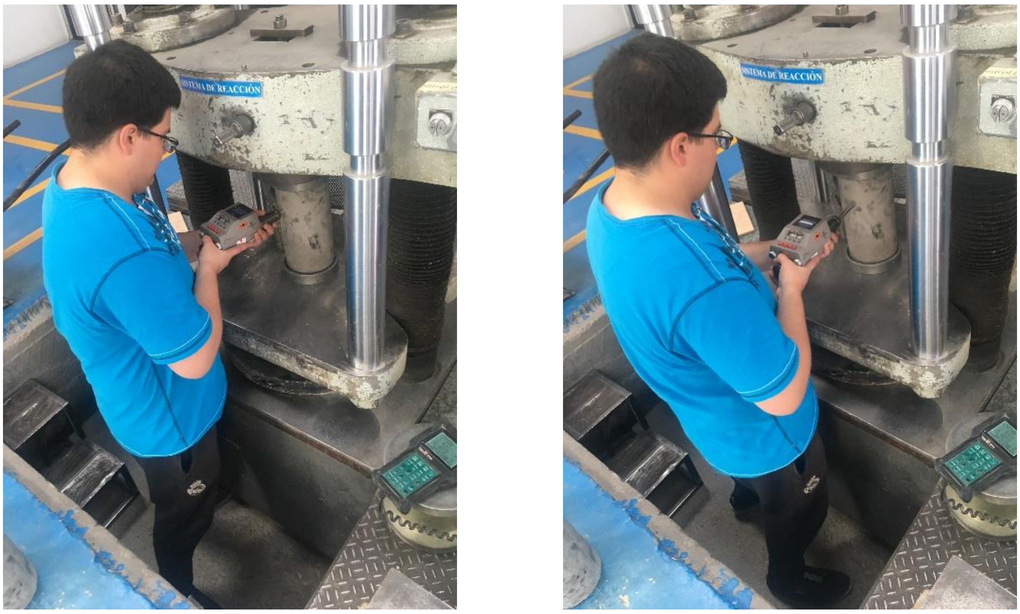


Fuente: Elaboración Propia

- Para el ensayo se debe realizar de 10 a 12 impactos máximo, según la norma ASTM C805 en el área previamente preparada. De estos 10 o 12 impactos se tiene que sacar el promedio y a este se lo llama número de rebote.
- Cada impacto que se realice debe tener una separación de por lo menos 2.5 a 3 cm para evitar dar más de un impacto en un punto determinado.
- Evitar dar el impacto en zonas porosas o que contengan grandes partículas de agregados.
- Aplicar una precarga de 40 Kilo newtons para mantener estático el cilindro.
- Sostener firmemente el martillo en una posición que permita que el embolo golpee perpendicularmente la superficie a ser ensayada. Se debe aumentar gradualmente la presión sobre el embolo hasta que se

realice el golpe. Entonces ahí será registrado el número de rebote por la impresora.

Figura 29. Ensayos de Índice de Rebote en Cilindros



Fuente: Elaboración Propia

- Realice una prueba de aproximadamente 10 impactos en cualquier superficie dura, cuando sea un día frio o si la maquina no ha sido utilizada en 3 meses.
- Registrar el número de rebote con por lo menos 2 cifras significativas.

Figura 30. Marcado de Puntos y Ensayo del Esclerómetro

Fuente: Elaboración Propia

2.5.5. Cálculos

Después de haber finalizado los ensayos, se calcula el valor promedio a partir de los datos obtenidos, se eliminan los datos que den error, es decir, que se desviaron más del 20% del valor promedio y se reemplazan por un impacto adicional. Luego se calcular el promedio nuevamente. Este valor promedio es el número de rebote (ASTM, 2016; Kamekura Seiki Co., 2016).

2.5.5.1. Corrección por dirección del impacto

Al usar el esclerómetro en superficies de inclinación horizontales, el valor de rebote debe corregirse según la siguiente fórmula propuesta en el manual de usuario del Concrete Test Hammer R-7500:

$$\mathrm{R} = \mathrm{R}_0 + \Delta\mathrm{R}$$

Donde:

R: Número de Rebote

R_0: Valor de rebote obtenido en el ensayo

ΔR: Valor de Corrección

El valor de corrección fue proporcionado por el Laboratorio de Materiales PUCE mediante en la Tabla 4:

Tabla 4. Factor de Corrección por Ángulo de Impacto

NÚMERO DE IMPACTO	**A -90°**	**B -90°**	**A 0°**	**B 0°**	**A +90°**	**B +90°**
1	80	79	80	80	81	81
2	80	79	80	79	81	81
3	79	80	80	79	81	81
4	79	80	80	80	80	80
5	81	78	80	80	80	80
6	80	80	80	80	81	81
7	79	80	80	80	81	81
8	80	80	80	80	81	81
9	80	78	80	80	81	81
10	81	79	80	80	81	81
Variación entre valores máximos	2	2	0	1	1	1
Promedio	79.9	79.3	80.0	79.8	80.8	80.8
Dispersión mayor	0.7	0.8	0.0	0.4	0.4	0.4

RESULTADOS:	**ANGULO**	**Factor de corrección**
	-90°	**1.00**
	0°	**1.00**

+90°	**0.99**

Fuente: Laboratorio de Materiales PUCE

Los valores de las columnas A, pertenecen a impactos realizados manteniendo el ángulo de calibración y el martillo siempre en la misma posición, mientras que los valores de las columnas B pertenecen a impactos realizados, manteniendo el ángulo de calibración, pero rotando el martille en diferentes posiciones a fin de simular las condiciones reales del uso del equipo en campo. Como se puede apreciar tanto las variaciones entre valores máximos como las dispersiones en los resultados evidencian confiabilidad del instrumento en su aplicación (PUCE, 2019).

2.5.5.2. Corrección del estado de humedad de la superficie

El siguiente valor ΔRw debe incluirse en el cálculo del valor del número de rebote realizado por el esclerómetro.

- Cuando la superficie de prueba este ligeramente húmedo se deberá usar el siguiente valor según el manual de usuario del Concrete Test Hammer R-7500:

$$\Delta R_w = +3$$

- Cuando la superficie de prueba se encuentra totalmente húmeda se deberá usar el siguiente valor según el manual de usuario del Concrete Test Hammer R-7500:

$$\Delta R_w = +5$$

2.5.5.3. Cálculo de la resistencia a compresión

- En Japón, la siguiente fórmula es utilizada para estimar la resistencia a la compresión del concreto hecho de cemento Portland:

$$F = 0.098 * (-184 + 13 * R) \quad \left[\frac{N}{mm^2}\right]$$

(Kamekura Seiki Co., 2016)

2.5.5.4. Factor por la edad del hormigón

Si la edad del hormigón no es de 28 días, la resistencia a la compresión se debe corregir de acuerdo en la Tabla 5 presentada por el manual de usuario del Concrete Test Hammer R-7500:

Tabla 5. Factor de Corrección por Edad del Hormigón

Edad (días)	10	20	28	50	100	150	200	300	500	1000	3000
$\boldsymbol{\alpha_n}$	1.55	1.12	1.00	0.87	0.78	0.74	0.72	0.70	0.67	0.65	0.63

Fuente: Manual de Usuario Concrete Test Hammer R-7500

$$F_c = F * \alpha_n \left[\frac{N}{mm^2}\right]$$

(Kamekura Seiki Co., 2016)

2.5.5.5. Fórmulas

Las fórmulas que se presentan a continuación según el manual del usuario del Concrete Test Hammer R-7500 se utilizaran para obtener el valor del número de rebote corregido y la resistencia a la compresión de cilindros utilizada en Japón y estas son:

$$R = R_0 * \frac{R_a}{R_{ao}} + \Delta R + \Delta R_w$$

(Kamekura Seiki Co., 2016)

Donde:

R: Número de Rebote

R_0: Valor de rebote obtenido en el ensayo

R_a: Valor Nominal del Yunque de prueba

R_{ao}: Valor Promedio de los resultados obtenidos del Yunque

ΔR: Valor de Corrección

ΔR_w: Valor de corrección del estado de humedad de la superficie

$$F_c = 0.098 * (-184 + 13 * R) * \alpha_n \left[\frac{N}{mm^2}\right]$$

(Kamekura Seiki Co., 2016)

Donde:

F_c: Resistencia a la compresión corregida

R: Numero de rebote

α_n: Factor por edad del hormigón

3. Resultados

3.1. Compresión Simple

En las tablas a continuación se muestran las diferentes resistencias que se han obtenido de cada uno de los ensayos a compresión simple dependiendo de su edad de 7, 28 días y cilindros proporcionados por la Hormigonera Holcim con una edad de 8 meses, todos los resultados mostrados son los obtenidos en laboratorio, en esta se muestra los valores de diámetro, altura, área, carga y su respectiva resistencia de cada uno de los cilindros.

Ya que el ensayo de compresión simple es el más utilizado puesto que da los resultados más confiables de las pruebas no destructivas del hormigón, los resultados presentados a continuación cumplen con lo estipulado por la norma ASTM C39, siendo así elegidos como base y referencia para la correlación de datos de las muestras ensayadas.

3.1.1. 7 días

Tabla 6. Cálculo de Resistencia a Compresión Simple 7 días

Probeta N°	Diámetro 1 (mm)	Diámetro 2 (mm)	Diámetro Promedio (cm)	Altura 1 (cm)	Altura 2 (cm)	Altura 3 (cm)	Altura Promedio (cm)	L/D	Área (cm2) A=π*(r^2/4)	Masa (Kg)	Carga (Kn)	Carga (Kg)	Resistencia a la compresión (Kg/cm2)
C1	151.82	152.09	15.20	30.00	30.50	30.50	30.3	2.0	181.35	11.66	170	17334.9	96
C2	151.74	151.74	15.17	30.10	30.10	30.00	30.1	2.0	180.84	11.65	167	17029.0	94
C3	151.91	151.37	15.16	30.10	30.00	30.00	30.0	2.0	180.60	11.67	177	18048.7	100
C4	151.66	152.67	15.22	29.50	30.10	30.00	29.9	2.0	181.85	11.81	400	40788.0	224
C5	149.39	150.28	14.98	29.70	29.90	29.80	29.8	2.0	176.33	11.52	385	39258.5	223
C6	153.47	153.62	15.35	30.30	30.20	30.20	30.2	2.0	185.17	11.90	352	35893.4	194
C7	154.57	153.86	15.42	30.00	30.00	30.00	30.0	1.9	186.79	12.48	320	32630.4	175
C8	153.33	152.39	15.29	30.60	30.10	30.00	30.2	2.0	183.52	12.11	208	21209.8	116
C9	152.82	153.17	15.30	30.50	30.10	30.00	30.2	2.0	183.84	12.20	194	19782.2	108
C10	151.17	151.16	15.12	30.00	29.90	29.90	29.9	2.0	179.47	12.21	174	17742.8	99
C11	151.67	151.96	15.18	30.40	30.50	30.10	30.3	2.0	181.02	12.31	210	21413.7	118
C12	153.39	153.25	15.33	30.40	30.50	30.50	30.5	2.0	184.62	12.72	203	20699.9	112
C13	151.10	150.57	15.08	29.50	29.60	29.50	29.5	2.0	178.69	11.75	369	37626.9	211
C14	151.84	152.29	15.21	29.50	29.50	29.60	29.5	1.9	181.61	11.84	353	35995.4	198
C15	135.40	135.50	13.55	30.00	30.10	30.10	30.1	2.2	144.09	12.05	183	18660.5	130
C16	151.90	152.50	15.22	30.10	30.00	30.20	30.1	2.0	181.94	12.28	140	14275.8	78
C17	149.70	150.90	15.03	29.90	30.00	30.00	30.0	2.0	177.42	11.95	157	16009.3	90
C18	152.60	152.20	15.24	30.40	30.30	30.30	30.3	2.0	182.41	12.57	302	30794.9	169

Probeta N°	Diámetro 1 (mm)	Diámetro 2 (mm)	Diámetro Promedio (cm)	Altura 1 (cm)	Altura 2 (cm)	Altura 3 (cm)	Altura Promedio (cm)	L/D	Área (cm2) A=π*(r^2/4)	Masa (Kg)	Carga (Kn)	Carga (Kg)	Resistencia a la compresión (Kg/cm2)
C19	151.40	151.50	15.15	30.40	30.40	30.50	30.4	2.0	180.15	12.49	321	32732.4	182
C20	150.30	153.00	15.17	30.00	30.00	30.00	30.0	2.0	180.62	12.28	318	32426.5	180
C21	152.00	151.59	15.18	30.30	30.40	30.40	30.4	2.0	180.97	12.49	239	24370.8	135
C22	151.11	151.39	15.13	30.40	30.20	30.50	30.4	2.0	179.67	12.64	240	24472.8	136
C23	151.75	152.10	15.19	30.50	30.50	30.50	30.5	2.0	181.28	13.12	378	38544.7	213
C24	152.23	153.34	15.28	30.50	30.70	30.50	30.6	2.0	183.34	13.27	488	49761.4	271
C25	150.25	150.32	15.03	30.20	30.30	30.50	30.3	2.0	177.39	12.57	406	41399.8	233
C26	151.32	151.45	15.14	30.10	30.40	30.50	30.3	2.0	179.99	12.45	390	39768.3	221
C27	151.49	151.67	15.16	30.50	30.40	30.40	30.4	2.0	180.46	13.01	467	47620.0	264
C28	151.49	151.62	15.16	30.50	30.50	30.40	30.5	2.0	180.40	13.08	451	45988.5	255
C29	151.68	151.97	15.18	30.50	30.50	30.40	30.5	2.0	181.04	13.00	485	49455.5	273
C30	150.05	150.63	15.03	30.00	29.60	29.80	29.8	2.0	177.52	11.44	294	29979.2	169
C31	153.40	153.79	15.36	30.40	30.50	30.40	30.4	2.0	185.29	12.09	288	29367.4	158
C32	151.57	151.75	15.17	30.40	30.50	30.30	30.4	2.0	180.65	11.78	299	30489.0	169
C33	151.23	152.32	15.18	30.00	30.00	28.50	29.5	1.9	180.92	12.80	236	24064.9	133
C34	151.99	151.55	15.18	29.90	29.50	29.90	29.8	2.0	180.91	12.67	363	37015.1	205
C35	152.37	151.46	15.19	30.00	29.90	29.90	29.9	2.0	181.26	12.81	269	27429.9	151
C36	152.28	152.84	15.26	30.30	30.20	30.10	30.2	2.0	182.80	12.39	265	27022.1	148
C37	151.08	150.44	15.08	29.70	29.60	29.50	29.6	2.0	178.51	11.75	222	22637.3	127

Probeta N°	Diámetro 1 (mm)	Diámetro 2 (mm)	Diámetro Promedio (cm)	Altura 1 (cm)	Altura 2 (cm)	Altura 3 (cm)	Altura Promedio (cm)	L/D	Área (cm2) A=π*(r^2/4)	Masa (Kg)	Carga (Kn)	Carga (Kg)	Resistencia a la compresión (Kg/cm2)
C38	150.15	149.89	15.00	29.50	29.60	29.60	29.6	2.0	176.76	11.63	242	24676.7	140
C39	151.27	151.48	15.14	30.00	29.80	30.20	30.0	2.0	179.97	12.25	258	26308.3	146
C40	152.97	152.82	15.29	30.20	30.10	30.40	30.2	2.0	183.60	12.72	197	20088.1	109
C41	151.48	151.68	15.16	29.90	30.10	30.00	30.0	2.0	180.46	12.18	266	27124.0	150
C42	154.08	153.94	15.40	30.00	30.00	30.00	30.0	1.9	186.29	12.12	400	40788.0	219
C43	157.07	152.52	15.48	30.00	30.00	30.00	30.0	1.9	188.19	11.89	393	40074.2	213
C44	150.88	150.85	15.09	30.00	29.90	29.80	29.9	2.0	178.76	11.54	270	27531.9	154
C45	152.94	152.47	15.27	30.00	30.00	30.00	30.0	2.0	183.15	11.90	305	31100.9	170
C46	153.04	154.08	15.36	30.00	30.00	30.00	30.0	2.0	185.20	12.25	359	36607.2	198
C47	152.61	153.13	15.29	30.00	30.00	30.00	30.0	2.0	183.54	12.30	370	37728.9	206
C48	150.79	150.38	15.06	29.80	29.80	30.00	29.9	2.0	178.10	11.65	547	55777.6	313
C49	151.57	150.65	15.11	29.00	29.90	29.80	29.6	2.0	179.34	11.66	582	59346.5	331
C50	153.92	153.07	15.35	30.40	30.00	30.20	30.2	2.0	185.05	12.11	541	55165.8	298
C51	151.70	151.84	15.18	30.50	30.30	30.40	30.4	2.0	180.91	12.09	421	42929.4	237
C52	150.22	150.45	15.03	29.90	29.90	29.90	29.9	2.0	177.50	11.67	392	39972.2	225
C53	153.70	152.88	15.33	30.40	30.30	30.40	30.4	2.0	184.55	12.36	384	39156.5	212
C54	151.60	153.00	15.23	30.60	30.50	30.50	30.5	2.0	182.18	12.44	272	27735.8	152
C55	153.40	153.40	15.34	30.40	30.50	30.30	30.4	2.0	184.82	12.77	375	38238.8	207
C56	150.80	152.20	15.15	30.50	30.50	30.60	30.5	2.0	180.27	12.52	342	34873.7	193
C57	151.81	151.39	15.16	29.90	30.00	29.90	29.9	2.0	180.50	12.35	334	34058.0	189

Probeta N°	Diámetro 1 (mm)	Diámetro 2 (mm)	Diámetro Promedio (cm)	Altura 1 (cm)	Altura 2 (cm)	Altura 3 (cm)	Altura Promedio (cm)	L/D	Área (cm2) A=π*(r^2/4)	Masa (Kg)	Carga (Kn)	Carga (Kg)	Resistencia a la compresión (Kg/cm2)
C58	151.98	152.09	15.20	30.40	30.40	30.40	30.4	2.0	181.54	12.59	334	34058.0	188
C59	152.10	153.67	15.29	30.30	32.00	33.00	31.8	2.08	183.58	12.07	296	30183.1	164
C60	153.30	151.98	15.26	32.00	30.20	29.70	30.6	2.01	182.99	11.93	315	32120.6	176
C61	151.15	151.37	15.13	29.60	29.70	29.80	29.7	1.96	179.70	11.47	283	28857.5	161
C62	151.18	151.04	15.11	29.60	30.00	29.60	29.7	1.97	179.34	11.50	284	28959.5	161
C63	150.91	150.66	15.08	29.40	29.30	29.50	29.4	1.95	178.57	11.44	308	31406.8	176
C64	150.45	149.30	14.99	29.90	29.70	29.90	29.8	1.99	176.42	11.43	286	29163.4	165
C65	150.76	149.86	15.03	29.20	29.40	29.50	29.4	1.95	177.45	11.37	300	30591.0	172
C66	151.41	151.37	15.14	29.80	29.80	29.90	29.8	1.97	180.00	11.77	310	31610.7	176
C67	150.12	151.72	15.09	30.60	30.70	30.70	30.7	2.03	178.89	12.18	144	14683.7	82
C68	154.19	152.09	15.31	30.80	30.25	30.40	30.5	1.99	184.19	12.10	152	15499.4	84
C69	152.26	148.59	15.04	30.10	30.30	30.00	30.1	2.00	177.72	11.83	149	15193.5	85
C70	154.79	148.95	15.19	30.10	30.10	30.20	30.1	1.98	181.15	11.75	145	14785.7	82

Fuente: Elaboración Propia

3.1.2. 28 días

Tabla 7. Cálculos de Resistencia a Compresión Simple 28 días

Probeta N°	Diámetro 1 (mm)	Diámetro 2 (mm)	Diámetro Promedio (cm)	Altura 1 (cm)	Altura 2 (cm)	Altura 3 (cm)	Altura Promedio (cm)	L/D	Área (cm2) A=π*(r^2/4)	Masa (Kg)	Carga (Kn)	Carga (Kg)	Resistencia (Kg/cm2)
C1	151.30	151.33	15.13	30.50	30.50	30.40	30.5	2.01	179.83	11.75	281	28653.6	159
C2	152.13	151.34	15.17	30.40	30.30	30.30	30.3	2.00	180.83	1.68	258	26308.3	145
C3	150.04	149.94	15.00	29.70	30.00	30.00	29.9	1.99	176.69	11.25	264	26920.1	152
C4	152.18	151.74	15.20	30.50	29.70	32.00	30.7	2.02	181.36	12.08	413	42113.6	232
C5	150.79	151.28	15.10	29.90	29.80	29.80	29.8	1.98	179.16	12.21	367	37423.0	209
C6	153.50	152.09	15.28	29.90	33.00	31.00	31.3	2.05	183.36	12.70	359	36607.2	200
C7	149.40	150.38	14.99	29.80	29.90	30.10	29.9	2.00	176.46	11.54	587	59856.4	339
C8	152.92	153.73	15.33	30.00	30.00	30.00	30.0	1.96	184.64	12.11	571	58224.9	315
C9	151.72	151.16	15.14	30.20	30.30	30.40	30.3	2.00	180.12	11.90	619	63119.4	350
C10	154.57	153.86	15.42	30.00	30.00	30.00	30.0	1.95	186.79	12.48	476	48537.7	260
C11	153.33	152.39	15.29	30.60	30.10	30.00	30.2	1.98	183.52	12.11	376	38340.7	282
C12	152.82	153.17	15.30	30.50	30.10	30.00	30.2	1.97	183.84	12.20	367	37423.0	204
C13	151.17	151.16	15.12	30.00	29.90	29.90	29.9	1.98	179.47	12.21	325	33140.3	185
C14	151.67	151.96	15.18	30.40	30.50	30.10	30.3	2.00	181.02	12.31	323	32936.3	182
C15	153.39	153.25	15.33	30.40	30.50	30.50	30.5	1.99	184.62	12.72	343	34975.7	189
C16	135.40	135.50	13.55	30.00	30.10	30.10	30.1	2.22	144.09	12.05	227	23147.2	161
C17	151.90	152.50	15.22	30.10	30.00	30.20	30.1	1.98	181.94	12.28	293	29877.2	164
C18	149.70	150.90	15.03	29.90	30.00	30.00	30.0	1.99	177.42	11.95	309	31508.7	178

Probeta N°	Diámetro 1 (mm)	Diámetro 2 (mm)	Diámetro Promedio (cm)	Altura 1 (cm)	Altura 2 (cm)	Altura 3 (cm)	Altura Promedio (cm)	L/D	Área (cm2) A=π*(r^2/4)	Masa (Kg)	Carga (Kn)	Carga (Kg)	Resistencia (Kg/cm2)
C19	152.60	152.20	15.24	30.40	30.30	30.30	30.3	1.99	182.41	12.57	350	35689.5	196
C20	151.40	151.50	15.15	30.40	30.40	30.50	30.4	2.01	180.15	12.49	378	38544.7	214
C21	150.30	153.00	15.17	30.00	30.00	30.00	30.0	1.98	180.62	12.28	367	37423.0	207
C22	150.25	150.32	15.03	30.20	30.30	30.50	30.3	2.02	177.39	12.57	312	31814.6	179
C23	151.32	151.45	15.14	30.10	30.40	30.50	30.3	2.00	179.99	12.45	333	33956.0	189
C24	151.68	151.97	15.18	30.50	30.50	30.40	30.5	2.01	181.04	13.00	367	37423.0	207
C25	151.49	151.67	15.16	30.50	30.40	30.40	30.4	2.01	180.46	13.01	528	53840.2	298
C26	151.49	151.62	15.16	30.50	30.50	30.40	30.5	2.01	180.40	13.08	531	54146.1	300
C27	151.68	151.97	15.18	30.50	30.50	30.40	30.5	2.01	181.04	13.00	584	59550.5	329
C28	153.70	154.43	15.41	30.40	30.20	30.30	30.3	1.97	186.42	11.97	535	54554.0	293
C29	150.60	151.47	15.10	29.50	29.80	29.40	29.6	1.96	179.16	11.04	438	44662.9	249
C30	150.81	154.95	15.29	30.30	30.10	30.20	30.2	1.98	183.57	11.80	506	51596.8	281
C31	149.89	150.50	15.02	29.90	29.90	30.10	30.0	2.00	177.17	12.52	383	39054.5	220
C32	152.16	150.92	15.15	30.10	29.30	29.60	29.7	1.96	180.36	12.39	476	48537.7	269
C33	151.44	152.25	15.18	30.10	30.10	29.50	29.9	1.97	181.09	12.87	378	38544.7	213
C34	154.23	154.15	15.42	30.10	30.00	30.10	30.1	1.95	186.72	12.14	427	43541.2	233
C35	150.92	151.10	15.10	29.50	29.70	29.50	29.6	1.96	179.10	11.48	375	38238.8	214
C36	151.12	150.88	15.10	30.00	29.90	30.00	30.0	1.98	179.08	11.83	336	34261.9	191
C37	151.27	151.48	15.14	30.00	29.80	30.20	30.0	1.98	179.97	12.25	352	35893.4	199

Probeta N°	Diámetro 1 (mm)	Diámetro 2 (mm)	Diámetro Promedio (cm)	Altura 1 (cm)	Altura 2 (cm)	Altura 3 (cm)	Altura Promedio (cm)	L/D	Área (cm2)	Masa (Kg)	Carga (Kn)	Carga (Kg)	Resistencia (Kg/cm2)
									A=π*(r^2/4)				
C38	152.97	152.82	15.29	30.20	30.10	30.40	30.2	1.98	183.60	12.72	408	41603.8	227
C39	151.48	151.68	15.16	29.90	30.10	30.00	30.0	1.98	180.46	12.18	500	50985.0	283
C40	152.75	151.92	15.23	30.50	30.50	30.40	30.5	2.00	182.26	12.54	437	44560.9	244
C41	150.73	150.86	15.08	30.30	30.30	30.40	30.3	2.01	178.59	12.36	427	43541.2	244
C42	150.69	150.11	15.04	30.20	30.20	30.30	30.2	2.01	177.66	12.28	461	47008.2	265
C43	150.11	151.34	15.07	29.40	29.50	29.50	29.5	1.95	178.43	11.94	315	32120.6	180
C44	152.41	151.75	15.21	29.90	29.70	30.10	29.9	1.97	181.65	12.31	320	32630.4	180
C45	151.79	152.25	15.20	30.10	29.90	30.10	30.0	1.98	181.51	12.42	362	36913.1	203
C46	150.25	150.32	15.03	30.20	30.30	30.50	30.3	2.02	177.39	12.57	292	29775.2	168
C47	151.32	151.45	15.14	30.10	30.40	30.30	30.3	2.00	179.99	12.45	367	37423.0	208
C48	151.68	151.97	15.18	30.50	30.50	30.40	30.5	2.01	181.04	13.00	273	27837.8	154
C49	151.49	151.67	15.16	30.50	30.40	30.40	30.4	2.01	180.46	13.01	487	49659.4	275
C50	151.49	151.62	15.16	30.50	30.50	30.40	30.5	2.01	180.40	13.08	357	36403.3	202
C51	151.68	151.97	15.18	30.50	30.50	30.40	30.5	2.01	181.04	13.00	250	25492.5	141
C52	154.08	153.94	15.40	30.00	30.00	30.00	30.0	1.95	186.29	12.20	400	40788.0	219
C53	157.07	152.52	15.48	30.00	30.00	30.00	30.0	1.94	188.19	11.89	393	40074.2	213
C54	150.88	150.85	15.09	29.90	29.90	29.90	29.9	1.98	178.76	11.54	270	27531.9	154
C55	152.75	151.92	15.23	30.50	30.50	30.40	30.5	2.00	182.26	12.54	502	51188.9	281
C56	150.73	150.86	15.08	30.30	30.30	30.40	30.3	2.01	178.59	12.36	508	51800.8	290
C57	150.69	150.11	15.04	30.20	30.20	30.30	30.2	2.01	177.66	12.28	495	50475.2	284

Probeta N°	Diámetro 1 (mm)	Diámetro 2 (mm)	Diámetro Promedio (cm)	Altura 1 (cm)	Altura 2 (cm)	Altura 3 (cm)	Altura Promedio (cm)	L/D	Área (cm2) A=π*(r^2/4)	Masa (Kg)	Carga (Kn)	Carga (Kg)	Resistencia (Kg/cm2)
C58	150.16	150.87	15.05	30.30	30.30	30.30	30.3	2.01	177.93	12.20	745	75967.7	427
C59	152.42	152.38	15.24	30.20	30.20	30.00	30.1	1.98	182.41	11.88	748	76273.6	418
C60	149.15	150.14	14.96	30.00	30.00	29.90	30.0	2.00	175.88	11.61	750	76477.5	435
C61	151.70	151.84	15.18	30.50	30.30	30.40	30.4	2.00	180.91	12.09	497	50679.1	280
C62	150.22	150.45	15.03	29.90	29.90	29.80	29.9	1.99	177.50	11.67	469	47823.9	269
C63	153.70	152.88	15.33	30.40	30.30	30.40	30.4	1.98	184.55	12.36	506	51596.8	280
C64	152.75	151.92	15.23	30.50	30.50	30.40	30.5	2.00	182.26	12.54	496	50577.1	278
C65	150.73	150.86	15.08	30.30	30.30	30.40	30.3	2.01	178.59	12.36	510	52004.7	291
C66	150.69	150.11	15.04	30.20	30.20	30.30	30.2	2.01	177.66	12.28	478	48741.7	274
C67	154.28	152.34	15.33	30.40	30.60	30.30	30.4	1.99	184.60	12.51	509	51902.7	281
C68	151.82	151.95	15.19	30.30	30.30	30.30	30.3	1.99	181.18	12.43	486	49557.4	274
C69	151.16	152.08	15.16	30.40	30.40	30.40	30.4	2.01	180.55	12.50	449	45784.5	254
C70	149.07	149.23	14.92	29.90	30.00	29.80	29.9	2.00	174.72	11.94	483	49251.5	282

Fuente: Elaboración Propia

3.1.3. Análisis de Resultados

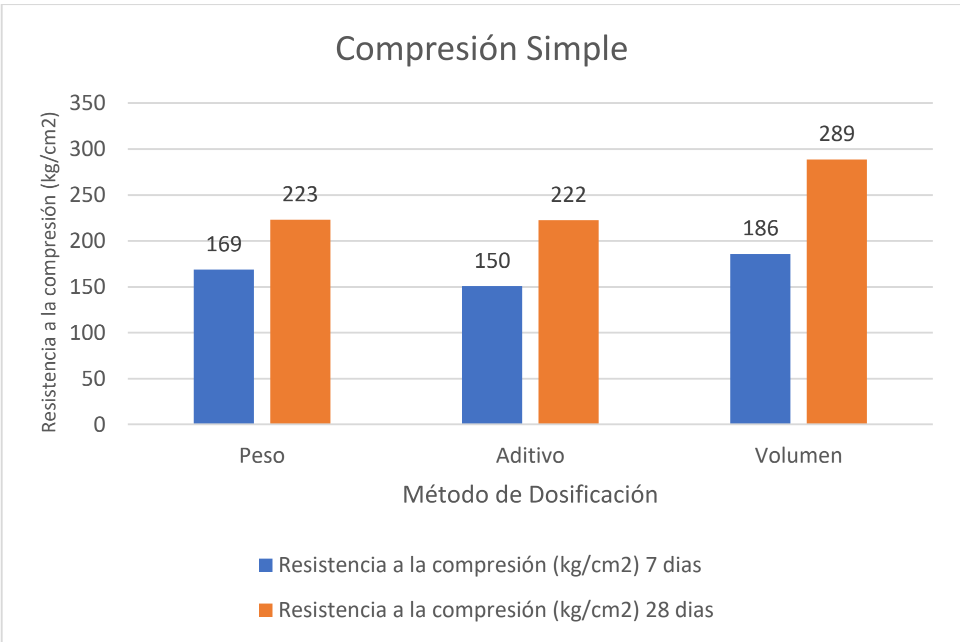
Tabla 8. Promedio de Resultados Compresión Simple

Edad	Método de Dosificación	Resistencia a la compresión (kg/cm2)
7	Peso	169
	Aditivo	150
	Volumen	186
28	Peso	223
	Aditivo	222
	Volumen	289

Fuente: Elaboración Propia

En la Figura 31 se observa el crecimiento progresivo de las muestras ensayadas a resistencia a la compresión simple a los 7 y 28 días, se puede observar claramente que los mejores resultados para esta son los que se presentan en el método de dosificación al volumen.

Figura 31. Análisis de Resultados Compresión Simple



Fuente: Elaboración Propia

3.1.4. Holcim (8 meses)

Tabla 9. Cálculos de Resistencia a Compresión Simple Holcim

Probeta N°	Diámetro 1 (mm)	Diámetro 2 (mm)	Diámetro Promedio (cm)	Altura 1 (cm)	Altura 2 (cm)	Altura 3 (cm)	Altura Promedio (cm)	L/D	Área (cm2) A=π*(r^2/4)	Masa (Kg)	Carga (Kn)	Carga (Kg)	Resistencia a la Compresión (Kg/cm2)
C1	148.97	148.70	14.88	30.00	30.00	30.00	30.0	2.02	173.98	11.93	1090	111147.3	639
C2	149.10	150.50	14.98	30.00	30.00	30.00	30.0	2.00	176.24	12.22	1075	109617.8	622
C3	149.32	149.00	14.92	30.00	29.90	30.00	30.0	2.01	174.74	11.91	612	62405.6	357
C4	148.78	150.93	14.99	29.80	29.90	29.80	29.8	1.99	176.37	12.07	991	101052.3	573
C5	149.30	149.45	14.94	30.00	30.00	30.00	30.0	2.01	175.25	12.05	874	89121.8	509
C6	149.60	149.72	14.97	29.50	29.60	29.60	29.6	1.98	175.91	11.92	880	89733.6	510
C7	149.07	149.23	14.92	29.90	30.00	29.80	29.9	2.00	174.72	11.94	483	49251.5	282
C8	149.41	149.61	14.95	29.90	29.90	29.80	29.9	2.00	175.56	12.19	877	89427.7	509
C9	148.73	150.23	14.95	29.90	29.90	29.80	29.9	2.00	175.49	11.87	794	80964.2	461
C10	150.21	150.01	15.01	30.00	29.80	29.90	29.9	1.99	176.97	11.78	1295	132051.2	746
C11	151.02	150.62	15.08	30.30	30.10	30.20	30.2	2.00	178.65	12.35	812	82799.6	463
C12	150.64	151.85	15.12	30.10	30.00	30.10	30.1	1.99	179.66	12.33	913	93098.6	518
C13	150.57	150.35	15.05	30.30	30.20	30.40	30.3	2.01	177.80	12.30	863	88000.1	495
C14	149.64	151.33	15.05	29.60	29.50	29.60	29.6	1.96	177.86	11.91	962	98095.1	552
C15	150.53	151.01	15.08	30.20	30.30	30.20	30.2	2.01	178.53	12.41	905	92282.9	517
C16	150.36	150.87	15.06	29.90	29.70	29.80	29.8	1.98	178.17	11.83	880	89733.6	504
C17	149.33	149.01	14.92	29.70	29.80	30.00	29.8	2.00	174.76	12.03	654	66688.4	382
C18	151.33	150.71	15.10	29.70	29.60	29.70	29.7	1.96	179.13	11.88	780	79536.6	444
C19	150.62	152.45	15.15	30.20	30.00	30.20	30.1	1.99	180.35	12.01	668	68116.0	378
C20	149.15	150.14	14.96	30.00	30.00	29.90	30.0	2.00	175.88	11.61	750	76477.5	435

Fuente: Elaboración Propia

3.2. Ultrasonido

En las tablas presentadas a continuación mostraremos los resultados obtenidos de los equipos de ultrasonido utilizados dando como resultado su velocidad de propagación de onda para cada uno de los cilindros ensayados en las diferentes edades de 7 y 28 días y finalmente para las muestras obtenidas de la Hormigonera Holcim con edad de 8 meses, en estos se observa que se ha cumplido con todos los parámetros estipulados por la norma ASTM C597 y determinando la calidad del hormigón mediante la tabla presentada en los anteriores capítulos dándonos como resultado que el hormigón ensayado en esta investigación es considerado de buena calidad, cabe recalcar que estos datos serán utilizados como base y referencia para las correlaciones presentadas a continuación.

3.2.1. 7 días

Tabla 10. Cálculos de Velocidad de Propagación de Onda 7 días

Probeta N°	Ultrasonido Tico					Calidad del Hormigón	Ultrasonido Elsonic ESI/P-10					Calidad del Hormigón	Resistencia a la compresión (kg/cm2)
	Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		
C1	114.7	114.2	0.0001145	0.000303	2.65	Regular	120.6	121.5	0.0001211	0.000303	2.51	Regular	96
C2	115.9	116.2	0.0001161	0.000301	2.59	Regular	112.8	114.7	0.0001138	0.000301	2.64	Regular	94
C3	108.6	107.7	0.0001082	0.000300	2.78	Regular	114.8	115.5	0.0001152	0.000300	2.61	Regular	100
C4	82.4	83.3	0.0000829	0.000299	3.60	Buena	90.1	91	0.0000906	0.000299	3.30	Buena	224
C5	78.5	80.1	0.0000793	0.000298	3.76	Buena	88.5	87.9	0.0000882	0.000298	3.38	Buena	223
C6	88.9	90.1	0.0000895	0.000302	3.38	Buena	90.5	92.3	0.0000914	0.000302	3.31	Buena	194
C7	84.8	85.1	0.0000850	0.000300	3.53	Buena	96.2	97.1	0.0000967	0.000300	3.10	Buena	175
C8	86.8	87.4	0.0000871	0.000302	3.47	Buena	95.8	94.5	0.0000952	0.000302	3.18	Buena	116
C9	92.7	91.3	0.0000920	0.000302	3.28	Buena	97.6	98.4	0.0000980	0.000302	3.08	Buena	108
C10	99.7	97.7	0.0000987	0.000299	3.03	Buena	103.2	103.7	0.0001035	0.000299	2.89	Regular	99
C11	92.7	98.6	0.0000957	0.000303	3.17	Buena	103.5	103.4	0.0001035	0.000303	2.93	Regular	118
C12	96.8	99.2	0.0000980	0.000305	3.11	Buena	105.5	101.5	0.0001035	0.000305	2.94	Regular	112
C13	101.3	102.2	0.0001018	0.000295	2.90	Regular	91.3	91.1	0.0000912	0.000295	3.24	Buena	211
C14	76.9	73.5	0.0000752	0.000295	3.93	Buena	89.6	90	0.0000898	0.000295	3.29	Buena	198
C15	113.6	109.6	0.0001116	0.000301	2.69	Regular	98.5	98	0.0000983	0.000301	3.06	Buena	130
C16	111.5	120.8	0.0001162	0.000301	2.59	Regular	101.6	99.9	0.0001008	0.000301	2.99	Regular	78
C17	109.6	109.6	0.0001096	0.000300	2.73	Regular	98	99	0.0000985	0.000300	3.04	Buena	90
C18	103.6	104.5	0.0001041	0.000303	2.92	Regular	93.2	94.6	0.0000939	0.000303	3.23	Buena	169
C19	104.5	102.4	0.0001035	0.000304	2.94	Regular	93.5	93.2	0.0000934	0.000304	3.26	Buena	182
C20	75.4	76.5	0.0000760	0.000300	3.95	Buena	91.2	91.1	0.0000912	0.000300	3.29	Buena	180
C21	97.3	94.4	0.0000959	0.000304	3.17	Buena	107.3	107.2	0.0001073	0.000304	2.83	Regular	135

Probeta N°	Ultrasonido Tico					Calidad del Hormigón	Ultrasonido Elsonic ESI/P-10					Calidad del Hormigón	Resistencia a la compresión (kg/cm2)
	Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		
C22	93.5	94.3	0.0000939	0.000304	3.23	Buena	104.4	104.1	0.0001043	0.000304	2.91	Regular	136
C23	85.6	85.5	0.0000856	0.000305	3.57	Buena	95.4	95.4	0.0000954	0.000305	3.20	Buena	213
C24	85.7	86.1	0.0000859	0.000306	3.56	Buena	95.5	95.6	0.0000956	0.000306	3.20	Buena	271
C25	89.1	89.1	0.0000891	0.000303	3.40	Buena	94	94.5	0.0000943	0.000303	3.22	Buena	233
C26	82.1	83.1	0.0000826	0.000303	3.67	Buena	93.3	93	0.0000932	0.000303	3.26	Buena	221
C27	86	85.8	0.0000859	0.000304	3.54	Buena	96	96.5	0.0000963	0.000304	3.16	Buena	264
C28	85.3	86.1	0.0000857	0.000305	3.56	Buena	96.1	96.6	0.0000964	0.000305	3.16	Buena	255
C29	83.6	84.1	0.0000839	0.000305	3.63	Buena	95.6	95	0.0000953	0.000305	3.20	Buena	273
C30	106.1	105.3	0.0001057	0.000298	2.82	Regular	109.1	108.4	0.0001088	0.000298	2.74	Regular	169
C31	108.1	105	0.0001066	0.000304	2.86	Regular	113.8	114.8	0.0001143	0.000304	2.66	Regular	158
C32	101	100	0.0001005	0.000304	3.02	Buena	109	110.3	0.0001097	0.000304	2.77	Regular	169
C33	88.1	89.7	0.0000889	0.000295	3.32	Buena	98.9	98.4	0.0000987	0.000295	2.99	Regular	133
C34	85	84.1	0.0000846	0.000298	3.52	Buena	95.4	95.3	0.0000954	0.000298	3.12	Buena	205
C35	124	120.2	0.0001221	0.000299	2.45	Regular	100.4	96.5	0.0000985	0.000299	3.04	Buena	151
C36	120.1	118.2	0.0001192	0.000302	2.53	Regular	96.1	96	0.0000961	0.000302	3.14	Buena	148
C37	128.1	120.1	0.0001241	0.000296	2.39	Regular	97.1	96.4	0.0000968	0.000296	3.06	Buena	127
C38	112.2	109.12	0.0001107	0.000296	2.67	Regular	94.5	95.2	0.0000949	0.000296	3.12	Buena	140
C39	79.8	82	0.0000809	0.000300	3.71	Buena	89.3	89.1	0.0000892	0.000300	3.36	Buena	146
C40	76.5	77.8	0.0000772	0.000302	3.92	Buena	89.1	89.3	0.0000892	0.000302	3.39	Buena	109
C41	104.1	106	0.0001051	0.000300	2.86	Regular	88.3	87.8	0.0000881	0.000300	3.41	Buena	150
C42	100.5	103.5	0.0001020	0.000300	2.94	Regular	107.8	106.8	0.0001073	0.000300	2.80	Regular	219
C43	99.4	97.3	0.0000984	0.000300	3.05	Buena	105.7	106.8	0.0001063	0.000300	2.82	Regular	213
C44	102.3	99.4	0.0001009	0.000299	2.96	Regular	104.3	104	0.0001042	0.000299	2.87	Regular	154

Probeta N°	Ultrasonido Tico					Calidad del Hormigón	Ultrasonido Elsonic ESI/P-10					Calidad del Hormigón	Resistencia a la compresión (kg/cm2)
	Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		
C45	90	90	0.0000900	0.000300	3.33	Buena	100.2	100.5	0.0001004	0.000300	2.99	Regular	170
C46	121.1	116.1	0.0001186	0.000300	2.53	Regular	101.7	98.4	0.0001001	0.000300	3.00	Regular	198
C47	127.2	122	0.0001246	0.000300	2.41	Regular	102	99.6	0.0001008	0.000300	2.98	Regular	206
C48	103	102.5	0.0001028	0.000299	2.91	Regular	86.9	87.1	0.0000870	0.000299	3.43	Buena	313
C49	76.9	76.8	0.0000769	0.000296	3.85	Buena	86.7	87	0.0000869	0.000296	3.40	Buena	331
C50	76.7	76.7	0.0000767	0.000302	3.94	Buena	87.4	87.6	0.0000875	0.000302	3.45	Buena	298
C51	90.2	94	0.0000921	0.000304	3.30	Buena	95.3	94.4	0.0000949	0.000304	3.21	Buena	237
C52	114	112.1	0.0001131	0.000299	2.64	Regular	93.5	92.5	0.0000930	0.000299	3.22	Buena	225
C53	83.6	89	0.0000863	0.000304	3.52	Buena	94.4	93.8	0.0000941	0.000304	3.23	Buena	212
C54	115.7	114.3	0.0001150	0.000305	2.66	Regular	96.5	97.1	0.0000968	0.000305	3.15	Buena	152
C55	109.4	115.4	0.0001124	0.000304	2.70	Regular	95.4	94.9	0.0000952	0.000304	3.19	Buena	207
C56	109.4	109.4	0.0001094	0.000305	2.79	Regular	93.2	93.1	0.0000932	0.000305	3.28	Buena	193
C57	117.2	111	0.0001141	0.000299	2.62	Regular	92.1	94.2	0.0000932	0.000299	3.21	Buena	189
C58	85.2	85	0.0000851	0.000304	3.57	Buena	95	94.6	0.0000948	0.000304	3.21	Buena	188
C59	89.6	89.4	0.0000895	0.000318	3.55	Buena	100.7	100.6	0.0001007	0.000318	3.16	Buena	164
C60	98.8	96.8	0.0000978	0.000306	3.13	Buena	100.5	99.5	0.0001000	0.000306	3.06	Buena	176
C61	92.7	94.7	0.0000937	0.000297	3.17	Buena	98.4	98.7	0.0000986	0.000297	3.01	Buena	161
C62	92.7	89.7	0.0000912	0.000297	3.26	Buena	98.9	98.2	0.0000986	0.000297	3.02	Buena	161
C63	87.3	86.3	0.0000868	0.000294	3.39	Buena	97.2	97.2	0.0000972	0.000294	3.02	Buena	176
C64	90.7	92.7	0.0000917	0.000298	3.25	Buena	97	96.9	0.0000970	0.000298	3.08	Buena	165
C65	92.8	92.8	0.0000928	0.000294	3.16	Buena	96.6	97.3	0.0000970	0.000294	3.03	Buena	172
C66	87.8	86.8	0.0000873	0.000298	3.42	Buena	95.6	95.9	0.0000958	0.000298	3.12	Buena	176
C67	98.7	99.6	0.0000992	0.000307	3.09	Buena	102.1	102	0.0001021	0.000307	3.01	Buena	82

Probeta N°	Ultrasonido Tico					Calidad del Hormigón	Ultrasonido Elsonic ESI/P-10					Calidad del Hormigón	Resistencia a la compresión (kg/cm2)
	Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		
C68	96.7	94.3	0.0000955	0.000305	3.19	Buena	100.1	99.6	0.0000999	0.000305	3.05	Buena	84
C69	92.7	93.1	0.0000929	0.000301	3.24	Buena	101.9	102.9	0.0001024	0.000301	2.94	Regular	85
C70	97.6	98.8	0.0000982	0.000301	3.07	Buena	100.9	100.6	0.0001008	0.000301	2.99	Regular	82

Fuente: Elaboración Propia

3.2.2. 28 días

Tabla 11. Cálculos de Velocidad de Propagación de Onda 28 días

Probeta N°	Altura Promedio (cm)	Ultrasonido Tico					Calidad del Hormigón	Ultrasonido Elsonic ESI/P-10					Calidad del Hormigón	Resistencia a la compresión (kg/cm2)
		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		
C1	30.5	100.9	102.7	0.0001018	0.000305	2.99	Regular	109.7	109.3	0.0001095	0.000305	2.78	Regular	159
C2	30.3	96.7	97.7	0.0000972	0.000303	3.12	Buena	108.3	108.4	0.0001084	0.000303	2.80	Regular	145
C3	29.9	102.7	100.9	0.0001018	0.000299	2.94	Regular	108.7	108.6	0.0001087	0.000299	2.75	Regular	152
C4	30.7	110.9	109.7	0.0001103	0.000307	2.79	Regular	96.1	96.3	0.0000962	0.000307	3.19	Buena	232
C5	29.8	115.8	115.9	0.0001159	0.000298	2.58	Regular	97.8	97.6	0.0000977	0.000298	3.05	Buena	209
C6	31.3	85.8	85.8	0.0000858	0.000313	3.65	Buena	95.5	95.1	0.0000953	0.000313	3.28	Buena	200
C7	29.9	99.8	76.4	0.0000881	0.000299	3.40	Buena	86.2	86.2	0.0000862	0.000299	3.47	Buena	339
C8	30.0	79.7	103.8	0.0000918	0.000300	3.27	Buena	88.3	88.1	0.0000882	0.000300	3.40	Buena	315
C9	30.3	103.5	101.7	0.0001026	0.000303	2.95	Regular	87.1	87.6	0.0000874	0.000303	3.47	Buena	350
C10	30.0	77.4	78.2	0.0000778	0.000300	3.86	Buena	91	90.5	0.0000908	0.000300	3.31	Buena	260
C11	30.2	80.3	81.8	0.0000811	0.000302	3.73	Buena	90.6	90.1	0.0000904	0.000302	3.35	Buena	282
C12	30.2	77.4	77.5	0.0000775	0.000302	3.90	Buena	89	88.8	0.0000889	0.000302	3.40	Buena	204
C13	29.9	85.5	85.7	0.0000856	0.000299	3.50	Buena	95.5	95.1	0.0000953	0.000299	3.14	Buena	185
C14	30.3	89.9	84.7	0.0000873	0.000303	3.47	Buena	95.2	94.7	0.0000950	0.000303	3.19	Buena	182
C15	30.5	86.6	86.7	0.0000867	0.000305	3.52	Buena	95.7	95.3	0.0000955	0.000305	3.19	Buena	189
C16	30.1	87	87.9	0.0000875	0.000301	3.44	Buena	95.9	96	0.0000960	0.000301	3.13	Buena	161
C17	30.1	83	82.9	0.0000830	0.000301	3.63	Buena	94.2	94.4	0.0000943	0.000301	3.19	Buena	164
C18	30.0	80.4	80.6	0.0000805	0.000300	3.72	Buena	94.6	94.7	0.0000947	0.000300	3.17	Buena	178
C19	30.3	77.9	81.9	0.0000799	0.000303	3.80	Buena	90.2	92.6	0.0000914	0.000303	3.32	Buena	196
C20	30.4	76	73.9	0.0000750	0.000304	4.06	Buena	86.1	87.7	0.0000869	0.000304	3.50	Buena	214
C21	30.0	75.4	76.5	0.0000760	0.000300	3.95	Buena	87.8	87.7	0.0000878	0.000300	3.42	Buena	207

Probeta N°	Altura Promedio (cm)	Ultrasonido Tico					Calidad del Hormigón	Ultrasonido Elsonic ESI/P-10					Calidad del Hormigón	Resistencia a la compresión (kg/cm2)
		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		
C22	30.3	92.7	94.7	0.0000937	0.000303	3.24	Buena	98.4	98.7	0.0000986	0.000303	3.08	Buena	179
C23	30.3	92.7	89.7	0.0000912	0.000303	3.33	Buena	98.5	98.2	0.0000984	0.000303	3.08	Buena	189
C24	30.5	87.3	86.3	0.0000868	0.000305	3.51	Buena	97.2	97.2	0.0000972	0.000305	3.13	Buena	207
C25	30.4	77.4	77.8	0.0000776	0.000304	3.92	Buena	89.5	89.4	0.0000895	0.000304	3.40	Buena	298
C26	30.5	81.1	81.4	0.0000813	0.000305	3.75	Buena	90.1	90.3	0.0000902	0.000305	3.38	Buena	300
C27	30.5	77.9	77.6	0.0000778	0.000305	3.92	Buena	89.4	89.3	0.0000894	0.000305	3.41	Buena	329
C28	30.3	97.8	97.1	0.0000975	0.000303	3.11	Buena	105.5	104.5	0.0001050	0.000303	2.89	Regular	293
C29	29.6	99.1	99.2	0.0000992	0.000296	2.98	Regular	108.1	108.4	0.0001083	0.000296	2.73	Regular	249
C30	30.2	96.1	95.6	0.0000959	0.000302	3.15	Buena	104.5	105	0.0001048	0.000302	2.88	Regular	281
C31	30.0	94.2	93.2	0.0000937	0.000300	3.20	Buena	88.2	89.4	0.0000888	0.000300	3.37	Buena	220
C32	29.7	110.2	109.1	0.0001097	0.000297	2.71	Regular	89.3	91.7	0.0000905	0.000297	3.28	Buena	269
C33	29.9	104.4	111.1	0.0001078	0.000299	2.77	Regular	93	93.1	0.0000931	0.000299	3.21	Buena	213
C34	30.1	91.8	83.8	0.0000878	0.000301	3.42	Buena	86.9	86.6	0.0000868	0.000301	3.47	Buena	233
C35	29.6	74.7	74.8	0.0000748	0.000296	3.96	Buena	86.5	85.3	0.0000859	0.000296	3.44	Buena	214
C36	30.0	77.8	76.7	0.0000773	0.000300	3.88	Buena	85.9	86.2	0.0000861	0.000300	3.48	Buena	191
C37	30.0	103.7	103.8	0.0001038	0.000300	2.89	Regular	94.3	94.8	0.0000946	0.000300	3.17	Buena	199
C38	30.2	80.3	80.6	0.0000805	0.000302	3.76	Buena	92.7	92.8	0.0000928	0.000302	3.26	Buena	227
C39	30.0	83.8	82.7	0.0000833	0.000300	3.60	Buena	96	95.3	0.0000957	0.000300	3.14	Buena	283
C40	30.5	87	87.9	0.0000875	0.000305	3.48	Buena	95.9	96	0.0000960	0.000305	3.18	Buena	244
C41	30.3	83	82.9	0.0000830	0.000303	3.66	Buena	94.2	94.2	0.0000942	0.000303	3.22	Buena	244
C42	30.2	80.4	80.6	0.0000805	0.000302	3.76	Buena	94.6	94.7	0.0000947	0.000302	3.19	Buena	265
C43	29.5	79.6	79.7	0.0000797	0.000295	3.70	Buena	90.3	89.7	0.0000900	0.000295	3.27	Buena	180
C44	29.9	80.1	86.6	0.0000834	0.000299	3.59	Buena	90.6	91.2	0.0000909	0.000299	3.29	Buena	180

Probeta N°	Altura Promedio (cm)	Ultrasonido Tico					Calidad del Hormigón	Ultrasonido Elsonic ESI/P-10					Calidad del Hormigón	Resistencia a la compresión (kg/cm2)
		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		
C45	30.0	80.6	79.6	0.0000801	0.000300	3.75	Buena	91.4	91.1	0.0000913	0.000300	3.29	Buena	203
C46	30.3	82	81.6	0.0000818	0.000303	3.71	Buena	99.8	99.5	0.0000997	0.000303	3.04	Buena	168
C47	30.3	84.2	84.2	0.0000842	0.000303	3.59	Buena	92.4	92.3	0.0000924	0.000303	3.28	Buena	208
C48	30.5	81.3	81.6	0.0000815	0.000305	3.74	Buena	100.1	99.7	0.0000999	0.000305	3.05	Buena	154
C49	30.4	104.7	100.5	0.0001026	0.000304	2.97	Regular	92.7	91.8	0.0000923	0.000304	3.30	Buena	275
C50	30.5	78.5	77.1	0.0000778	0.000305	3.92	Buena	94.8	93.8	0.0000943	0.000305	3.23	Buena	202
C51	30.5	113.7	112.6	0.0001132	0.000305	2.69	Regular	100	98.7	0.0000994	0.000305	3.07	Buena	141
C52	30.0	103.5	101.6	0.0001026	0.000300	2.93	Regular	113.1	113.2	0.0001132	0.000300	2.65	Regular	219
C53	30.0	104.5	105	0.0001048	0.000300	2.86	Regular	114.7	114.1	0.0001144	0.000300	2.62	Regular	213
C54	29.9	103.6	104.7	0.0001042	0.000299	2.87	Regular	110.1	110.2	0.0001102	0.000299	2.71	Regular	154
C55	30.5	79.4	76.3	0.0000779	0.000305	3.91	Buena	93.3	92.4	0.0000929	0.000305	3.28	Buena	281
C56	30.3	77.3	76.3	0.0000768	0.000303	3.95	Buena	92.5	93.3	0.0000929	0.000303	3.27	Buena	290
C57	30.2	76	76.4	0.0000762	0.000302	3.97	Buena	89.8	89.9	0.0000899	0.000302	3.36	Buena	284
C58	30.3	74.8	74.6	0.0000747	0.000303	4.06	Buena	87	87.2	0.0000871	0.000303	3.48	Buena	427
C59	30.1	74	73.9	0.0000740	0.000301	4.07	Buena	86.3	86.5	0.0000864	0.000301	3.49	Buena	418
C60	30.0	70.8	70.9	0.0000709	0.000300	4.23	Buena	84.4	84.6	0.0000845	0.000300	3.55	Buena	435
C61	30.4	80	78.7	0.0000794	0.000304	3.83	Buena	90.7	90.6	0.0000907	0.000304	3.35	Buena	280
C62	29.9	80.9	80.2	0.0000806	0.000299	3.71	Buena	90.6	90.8	0.0000907	0.000299	3.29	Buena	269
C63	30.4	80.1	80.7	0.0000804	0.000304	3.78	Buena	90.2	90.5	0.0000904	0.000304	3.36	Buena	280
C64	30.5	79.4	76.3	0.0000779	0.000305	3.91	Buena	93.3	92.4	0.0000929	0.000305	3.28	Buena	278
C65	30.3	77.3	76.3	0.0000768	0.000303	3.95	Buena	92.5	93.3	0.0000929	0.000303	3.27	Buena	291
C66	30.2	76	76.4	0.0000762	0.000302	3.97	Buena	89.8	89.9	0.0000899	0.000302	3.36	Buena	274
C67	30.4	73.3	74.4	0.0000739	0.000304	4.12	Buena	89.4	89.3	0.0000894	0.000304	3.41	Buena	281

Probeta N°	Altura Promedio (cm)	Ultrasonido Tico					Calidad del Hormigón	Ultrasonido Elsonic ESI/P-10					Calidad del Hormigón	Resistencia a la compresión (kg/cm2)
		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		
C68	30.3	76.4	78.4	0.0000774	0.000303	3.91	Buena	91.5	91.7	0.0000916	0.000303	3.31	Buena	274
C69	30.4	72.3	72.1	0.0000722	0.000304	4.21	Buena	89.3	88.7	0.0000890	0.000304	3.42	Buena	254
C70	29.9	75.85	73.05	0.0000745	0.000299	4.02	Buena	88.95	89.55	0.0000893	0.000299	3.35	Buena	282

Fuente: Elaboración Propia

3.2.3. Análisis de resultados

Ultrasonido Tico:

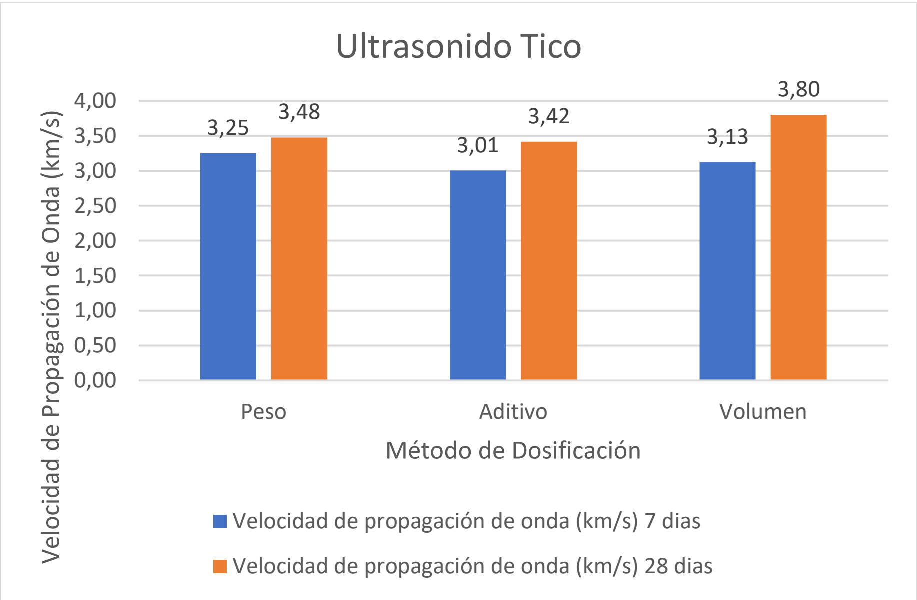
Tabla 12. Promedio de Resultados Ultrasonido Tico

Edad	**Método de Dosificación**	**Ultrasonido Tico**
		Velocidad de Propagación de Onda (Km/s)
7	Peso	3.25
	Aditivo	3.01
	Volumen	3.13
28	Peso	3.48
	Aditivo	3.42
	Volumen	3.80

Fuente: Elaboración Propia

En la Figura 32 se observa el crecimiento progresivo de las muestras ensayadas con el ultrasonido tico a los 7 y 28 días, se puede observar claramente que los mejores resultados para esta son los que se presentan en el método de dosificación al peso a los 7 días y a los 28 días se observa que el mejor resultado es para el método de dosificación al volumen.

Figura 32. Análisis de Resultados Ultrasonido Tico



Fuente: Elaboración Propia

Ultrasonido Elsonic ESI/P-10:

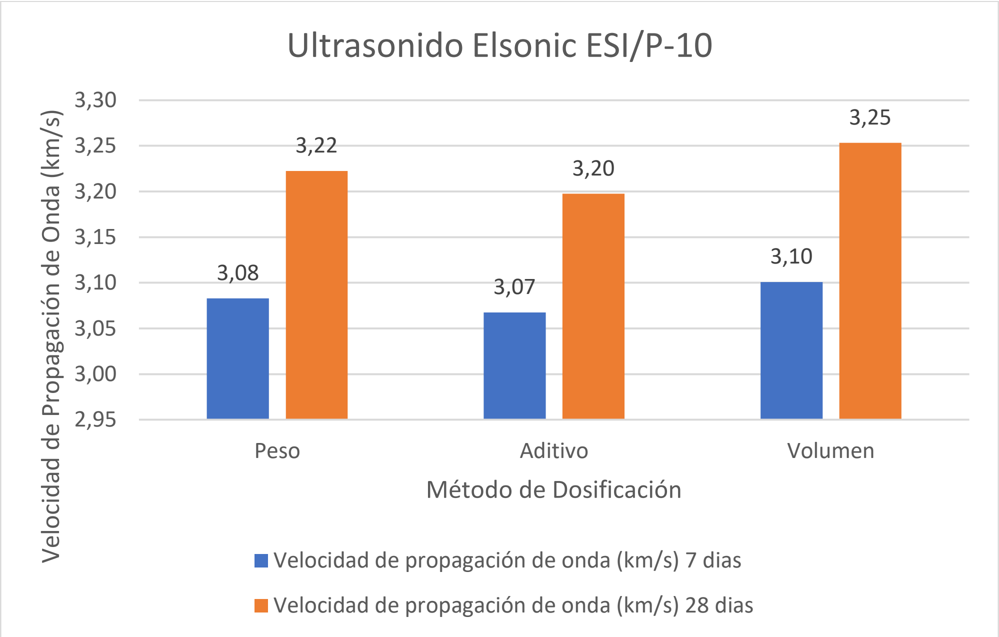
Tabla 13. Promedio de Resultados Ultrasonido Elsonic ESI/P-10

Edad	**Método de Dosificación**	**Ultrasonido Elsonic ESI/P-10**
		Velocidad de Propagación de Onda (Km/s)
7	Peso	3.08
	Aditivo	3.07
	Volumen	3.10
28	Peso	3.22
	Aditivo	3.20
	Volumen	3.25

Fuente: Elaboración Propia

En la Figura 33 se observa el crecimiento progresivo de las muestras ensayadas con el ultrasonido Elsonic ESI/P-10 a los 7 y 28 días, se puede observar claramente que los mejores resultados para esta son los que se presentan en el método de dosificación al volumen.

Figura 33. Análisis de Resultados Ultrasonido Elsonic ESI/P-10



Fuente: Elaboración Propia

3.2.4. Holcim (8 meses)

Tabla 14. Cálculos de Velocidad de Propagación de Onda Holcim

Probeta No.	Ultrasonido Tico					Calidad del Hormigón	Ultrasonido Elsonic ESI/P-10					Calidad del Hormigón
	Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)		Tiempo 1 (µs)	Tiempo 2 (µs)	Tiempo Promedio (s)	Distancia (Km)	Velocidad de propagación de Onda (Km/s)	
C1	72.35	71.90	0.0000721	0.000300	4.16	Buena	85.15	84.6	0.0000849	0.000300	3.53	Buena
C2	76.65	74.85	0.0000758	0.000300	3.96	Buena	84.75	85.1	0.0000849	0.000300	3.53	Buena
C3	101.90	100.50	0.0001012	0.000300	2.96	Regular	88.9	90.9	0.0000899	0.000300	3.33	Buena
C4	70.60	69.60	0.0000701	0.000298	4.26	Buena	84.05	84.1	0.0000841	0.000298	3.55	Buena
C5	73.35	74.75	0.0000741	0.000300	4.05	Buena	86.3	86.05	0.0000862	0.000300	3.48	Buena
C6	67.55	67.50	0.0000675	0.000296	4.38	Buena	84.4	85.3	0.0000849	0.000296	3.48	Buena
C7	75.85	73.05	0.0000745	0.000299	4.02	Buena	88.95	89.55	0.0000893	0.000299	3.35	Buena
C8	67.80	66.45	0.0000671	0.000299	4.45	Buena	83.4	83.25	0.0000833	0.000299	3.58	Buena
C9	66.95	67.20	0.0000671	0.000299	4.45	Buena	84.05	83.7	0.0000839	0.000299	3.56	Buena
C10	68.50	69.30	0.0000689	0.000299	4.34	Buena	83.3	83.45	0.0000834	0.000299	3.59	Buena
C11	72.65	69.35	0.0000710	0.000302	4.25	Buena	85.2	85.15	0.0000852	0.000302	3.55	Buena
C12	70.35	70.85	0.0000706	0.000301	4.26	Buena	86.1	86.1	0.0000861	0.000301	3.49	Buena
C13	70.30	71.20	0.0000708	0.000303	4.28	Buena	86.35	86.45	0.0000864	0.000303	3.51	Buena
C14	69.45	69.25	0.0000694	0.000296	4.26	Buena	85.4	85.5	0.0000855	0.000296	3.46	Buena
C15	69.55	69.35	0.0000695	0.000302	4.35	Buena	85.7	85.35	0.0000855	0.000302	3.54	Buena
C16	69.45	69.85	0.0000697	0.000298	4.28	Buena	85.9	85.65	0.0000858	0.000298	3.47	Buena
C17	69.70	68.70	0.0000692	0.000298	4.31	Buena	86.15	85.75	0.0000860	0.000298	3.47	Buena
C18	69.75	70.00	0.0000699	0.000297	4.25	Buena	86.1	86.2	0.0000862	0.000297	3.44	Buena
C19	96.80	95.50	0.0000962	0.000301	3.13	Buena	113.75	112.65	0.0001132	0.000301	2.66	Regular
C20	70.8	70.9	0.0000709	0.000300	4.23	Buena	84.4	84.6	0.0000845	0.000300	3.55	Buena

Fuente: Elaboración Propia

3.3. Esclerómetro

Los resultados que se obtuvieron en el laboratorio mientras se desarrollaba la prueba del esclerómetro su mostraran en las siguientes tablas, en estas se muestra los factores de corrección utilizados, el número de lecturas que fueron de 10 a 12 cumpliendo con la norma ASTM C805 para proceder a sacar el promedio de estos y así obtener su resistencia según el manual de usuario del equipo Concrete Test Hammer R-7500 a las edades de 7, 28 días y finalmente en cilindros proporcionados por la Hormigonera Holcim con edad de 8 meses, los resultados del índice de rebote serán tomados como base y referencia de las correlaciones realizadas en esta investigación.

3.3.1. 7 días

Tabla 15. Cálculos de Índice de Rebote 7 días

Probeta N°	Índice de Rebote												Promedio (Ro)	Factor de corrección por ángulo de impacto (ΔR)	Factor de corrección del estado de humedad de la superficie (ΔRw)	Valor Nominal del Yunque (Ra)	Promedio (Rao)	Ra/Rao	Índice de Rebote corregido (R)	Factor de corrección por edad del concreto (αn)	Resistencia a la compresión (kg/cm2)
	1	2	3	4	5	6	7	8	9	10	11	12		0	húmeda				R=Ro*(Ra/Rao) +ΔR+ΔRw	7	F=(-184+13*R) *αn
C1	15	14	16	15	15	14	16	15	14	16	-	-	15.0	1	5	80	79.8	1	21	1.68	150
C2	15	17	16	16	18	17	17	14	15	15	-	-	16.0	1	5	80	79.8	1	22	1.68	172
C3	16	18	16	17	15	14	17	16	14	16	-	-	15.9	1	5	80	79.8	1	22	1.68	170
C4	20	20	20	19	18	20	20	18	18	20	-	-	19.3	1	5	80	79.8	1	25	1.68	244
C5	16	19	19	20	19	21	16	21	15	15	-	-	18.1	1	5	80	79.8	1	24	1.68	218
C6	20	20	19	23	19	22	22	22	24	19	-	-	21.0	1	5	80	79.8	1	27	1.68	282
C7	18	19	17	19	24	23	21	22	20	19	-	-	20.2	1	5	80	79.8	1	26	1.68	264
C8	18	17	18	19	17	19	15	16	16	19	-	-	17.4	1	5	80	79.8	1	23	1.68	203
C9	19	18	19	19	17	15	17	16	19	19	-	-	17.8	1	5	80	79.8	1	24	1.68	212
C10	17	17	16	17	17	16	17	15	17	15	-	-	16.4	1	5	80	79.8	1	22	1.68	181
C11	19	20	17	18	20	20	18	21	22	21	-	-	19.6	1	5	80	79.8	1	26	1.68	251
C12	15	15	19	17	18	16	20	17	18	17	-	-	17.2	1	5	80	79.8	1	23	1.68	199
C13	20	21	17	18	17	21	17	21	20	21	-	-	19.3	1	5	80	79.8	1	25	1.68	244
C14	19	21	20	20	22	21	18	20	21	20	-	-	20.2	1	5	80	79.8	1	26	1.68	264
C15	13	16	15	15	14	16	15	14	18	16	-	-	15.2	1	5	80	79.8	1	21	1.68	155
C16	13	12	12	11	12	13	12	12	13	12	-	-	12.2	1	5	80	79.8	1	18	1.68	89
C17	13	13	15	13	16	16	16	15	14	14	-	-	14.5	1	5	80	79.8	1	21	1.68	139
C18	17	19	20	21	21	17	19	21	20	21	-	-	19.6	1	5	80	79.8	1	26	1.68	251
C19	19	20	19	22	19	20	19	16	18	18	-	-	19.0	1	5	80	79.8	1	25	1.68	238
C20	19	17	18	19	19	16	18	16	18	16	-	-	17.6	1	5	80	79.8	1	24	1.68	207
C21	19	19	21	20	20	25	24	25	18	19	-	-	21.0	1	5	80	79.8	1	27	1.68	282
C22	19	24	21	23	22	19	24	24	21	22	-	-	21.9	1	5	80	79.8	1	28	1.68	301
C23	29	26	27	26	28	31	31	29	29	31	-	-	28.7	1	5	80	79.8	1	35	1.68	450
C24	29	23	28	30	23	31	28	31	31	25	-	-	27.9	1	5	80	79.8	1	34	1.68	433

Probeta N°	índice de Rebote												Promedio (Ro)	Factor de corrección por ángulo de impacto (∆R)	Factor de corrección del estado de humedad de la superficie (∆Rw)	Valor Nominal del Yunque (Ra)	Promedio (Rao)	Ra/Rao	índice de Rebote corregido (R)	Factor de corrección por edad del concreto (αn)	Resistencia a la compresión (kg/cm2)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**		**0**	**húmeda**				**R=Ro*(Ra/Rao) +∆R+∆Rw**	**7**	**F=(-184+13*R) *αn**
C25	28	28	26	28	24	31	25	28	25	26	24	26	26.6	1	5	80	79.8	1	33	1.68	404
C26	22	19	24	24	23	19	26	25	26	27	25	20	23.3	1	5	80	79.8	1	29	1.68	333
C27	25	25	29	26	21	24	22	24	26	24	-	-	24.6	1	5	80	79.8	1	31	1.68	361
C28	28	22	24	30	26	26	30	26	27	29	-	-	26.8	1	5	80	79.8	1	33	1.68	409
C29	25	24	26	25	25	27	25	25	25	25	-	-	25.2	1	5	80	79.8	1	31	1.68	374
C30	18	19	21	19	22	19	24	23	21	21	-	-	20.7	1	5	80	79.8	1	27	1.68	275
C31	20	21	22	24	19	18	23	24	24	20	-	-	21.5	1	5	80	79.8	1	28	1.68	293
C32	23	21	22	24	23	27	24	24	22	24	-	-	23.4	1	5	80	79.8	1	29	1.68	334
C33	18	23	19	20	19	19	17	21	21	17	-	-	19.4	1	5	80	79.8	1	25	1.68	247
C34	20	21	22	21	22	23	23	19	19	19	-	-	20.9	1	5	80	79.8	1	27	1.68	280
C35	20	23	20	22	23	18	23	24	22	20	-	-	21.5	1	5	80	79.8	1	28	1.68	293
C36	20	20	22	18	17	18	20	21	20	19	-	-	19.5	1	5	80	79.8	1	26	1.68	249
C37	17	22	17	19	18	17	19	22	18	20	-	-	18.9	1	5	80	79.8	1	25	1.68	236
C38	17	15	19	20	15	18	20	17	17	19	-	-	17.7	1	5	80	79.8	1	24	1.68	209
C39	17	16	17	18	19	18	13	15	15	13	-	-	16.1	1	5	80	79.8	1	22	1.68	174
C40	20	16	16	15	17	16	20	19	18	21	-	-	17.8	1	5	80	79.8	1	24	1.68	212
C41	17	18	20	17	14	17	17	20	20	18	-	-	17.8	1	5	80	79.8	1	24	1.68	212
C42	22	22	24	24	25	27	26	23	24	22	23	25	23.9	1	5	80	79.8	1	30	1.68	346
C43	22	24	20	26	24	24	22	23	25	29	28	25	24.3	1	5	80	79.8	1	30	1.68	355
C44	25	23	22	24	25	26	26	25	23	24	22	23	24.0	1	5	80	79.8	1	30	1.68	347
C45	21	20	17	20	19	18	18	19	17	18	18	21	18.8	1	5	80	79.8	1	25	1.68	234
C46	24	19	18	22	23	20	24	26	20	23	19	24	21.8	1	5	80	79.8	1	28	1.68	300
C47	23	23	25	25	25	24	26	24	20	21	23	23	23.5	1	5	80	79.8	1	30	1.68	336
C48	23	23	24	28	25	30	27	29	29	29	-	-	26.7	1	5	80	79.8	1	33	1.68	407
C49	25	25	22	23	25	26	26	25	23	24	-	-	24.4	1	5	80	79.8	1	30	1.68	356

Probeta N°	Índice de Rebote												Promedio (Ro)	Factor de corrección por ángulo de impacto (∆R)	Factor de corrección del estado de humedad de la superficie (∆Rw)	Valor Nominal del Yunque (Ra)	Promedio (Rao)	Ra/Rao	Índice de Rebote corregido (R)	Factor de corrección por edad del concreto (αn)	Resistencia a la compresión (kg/cm2)
	1	2	3	4	5	6	7	8	9	10	11	12		0	húmeda				R=Ro*(Ra/Rao) +∆R+∆Rw	7	F=(-184+13*R) *αn
C50	29	27	23	29	27	27	29	29	28	29	-	-	27.7	1	5	80	79.8	1	34	1.68	428
C51	26	26	22	30	23	26	28	25	30	23	-	-	25.9	1	5	80	79.8	1	32	1.68	389
C52	20	22	23	26	24	26	26	24	26	26	-	-	24.3	1	5	80	79.8	1	30	1.68	354
C53	27	22	29	26	26	28	26	25	31	25	-	-	26.5	1	5	80	79.8	1	33	1.68	402
C54	19	19	19	20	21	23	23	22	24	23	22	23	21.5	1	5	80	79.8	1	28	1.68	293
C55	23	21	22	22	23	23	22	24	24	21	23	25	22.8	1	5	80	79.8	1	29	1.68	320
C56	22	21	20	22	22	20	23	22	22	22	22	21	21.6	1	5	80	79.8	1	28	1.68	294
C57	20	22	21	23	21	22	21	25	24	22	-	-	22.1	1	5	80	79.8	1	28	1.68	306
C58	18	21	22	22	23	22	22	23	22	21	-	-	21.6	1	5	80	79.8	1	28	1.68	295
C59	17	17	18	18	18	20	18	15	17	20	19	17	17.8	1	5	80	79.8	1	24	1.68	212
C60	17	18	21	24	21	18	22	21	20	20	21	21	20.3	1	5	80	79.8	1	26	1.68	267
C61	17	17	18	19	21	19	24	24	20	23	22	20	20.3	1	5	80	79.8	1	26	1.68	267
C62	15	15	17	17	21	21	19	18	18	19	19	16	17.9	1	5	80	79.8	1	24	1.68	214
C63	17	17	16	21	19	17	20	19	18	19	20	21	18.7	1	5	80	79.8	1	25	1.68	231
C64	17	17	17	18	18	18	21	21	21	17	19	21	18.8	1	5	80	79.8	1	25	1.68	232
C65	20	20	21	21	22	25	23	24	24	24	25	25	22.8	1	5	80	79.8	1	29	1.68	322
C66	22	24	19	24	19	22	24	24	19	23	23	19	21.8	1	5	80	79.8	1	28	1.68	300
C67	13	18	15	17	18	17	17	15	17	13	16	17	16.1	1	5	80	79.8	1	22	1.68	174
C68	13	12	15	14	16	16	17	14	17	13	17	13	14.8	1	5	80	79.8	1	21	1.68	145
C69	17	14	16	14	19	17	16	18	19	17	19	18	17.0	1	5	80	79.8	1	23	1.68	194
C70	14	14	15	15	12	17	14	13	13	14	14	13	14.0	1	5	80	79.8	1	20	1.68	128

Fuente: Elaboración Propia

3.3.2. 28 días

Tabla 16. Cálculo de Índice de Rebote 28 días

Probeta N°	índice de Rebote												Promedio (Ro)	Factor de corrección por ángulo de impacto (∆R)	Factor de corrección del estado de humedad de la superficie (∆Rw)	Valor Nominal del Yunque (Ra)	Promedio (Rao)	Ra/Rao	índice de Rebote corregido (R)	Factor de corrección por edad del concreto (αn)	Resistencia a la compresión (kg/cm2)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**		**0**	**seco**				**R=Ro*(Ra/Rao) +∆R+∆Rw**	**28**	**F=(-184+13*R) *αn**
C1	24	21	20	19	20	20	20	24	19	19	19	20	20.4	1	0	80	79.8	1	21	1	95
C2	18	20	22	19	23	22	22	21	21	17	20	17	20.2	1	0	80	79.8	1	21	1	92
C3	19	22	19	21	20	19	22	23	20	22	19	23	20.8	1	0	80	79.8	1	22	1	99
C4	21	22	23	24	23	24	23	23	23	23	21	23	22.8	1	0	80	79.8	1	24	1	125
C5	21	22	24	22	24	25	21	23	26	23	22	22	22.9	1	0	80	79.8	1	24	1	128
C6	23	22	24	24	22	23	24	24	22	22	22	22	22.8	1	0	80	79.8	1	24	1	127
C7	23	27	30	29	28	23	28	28	26	22	26	25	26.3	1	0	80	79.8	1	27	1	171
C8	24	26	23	27	28	29	26	27	31	24	24	23	26.0	1	0	80	79.8	1	27	1	168
C9	28	29	28	26	27	32	31	30	33	30	33	30	29.8	1	0	80	79.8	1	31	1	217
C10	26	21	25	26	26	28	27	26	29	30	21	26	25.9	1	0	80	79.8	1	27	1	167
C11	27	26	26	29	29	27	30	27	28	29	25	30	27.8	1	0	80	79.8	1	29	1	191
C12	21	23	21	25	19	22	19	23	23	22	19	21	21.5	1	0	80	79.8	1	23	1	109
C13	20	20	21	23	22	26	24	23	26	22	23	23	22.8	1	0	80	79.8	1	24	1	125
C14	22	24	22	22	21	25	26	22	21	24	21	23	22.8	1	0	80	79.8	1	24	1	125
C15	27	23	21	24	23	24	26	23	21	25	25	21	23.6	1	0	80	79.8	1	25	1	136
C16	23	23	22	22	24	20	25	23	24	20	21	20	22.3	1	0	80	79.8	1	23	1	119
C17	22	25	20	25	22	24	24	21	23	24	20	20	22.5	1	0	80	79.8	1	24	1	122
C18	18	21	18	20	23	23	25	24	20	24	24	22	21.8	1	0	80	79.8	1	23	1	114
C19	26	23	23	24	25	23	21	22	26	22	21	24	23.3	1	0	80	79.8	1	24	1	133
C20	26	23	24	26	25	26	23	21	23	21	23	22	23.6	1	0	80	79.8	1	25	1	136
C21	23	22	26	24	21	24	26	22	21	21	25	26	23.4	1	0	80	79.8	1	24	1	134
C22	24	24	23	27	26	26	25	24	25	25	22	24	24.6	1	0	80	79.8	1	26	1	149
C23	26	21	24	26	25	25	24	22	25	26	25	20	24.1	1	0	80	79.8	1	25	1	143
C24	21	21	22	26	26	22	26	21	21	22	19	19	22.2	1	0	80	79.8	1	23	1	118

Probeta N°	Índice de Rebote												Promedio (Ro)	Factor de corrección por ángulo de impacto (ΔR)	Factor de corrección del estado de humedad de la superficie (ΔRw)	Valor Nominal del Yunque (Ra)	Promedio (Rao)	Ra/Rao	Índice de Rebote corregido (R)	Factor de corrección por edad del concreto (αn)	Resistencia a la compresión (kg/cm2)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**		**0**	**seco**				**R=Ro*(Ra/Rao) +ΔR+ΔRw**	**28**	**F=(-184+13*R) *αn**
C25	26	24	27	28	29	25	26	28	29	29	29	27	27.3	1	0	80	79.8	1	28	1	184
C26	27	28	27	29	27	30	29	29	31	30	29	29	28.8	1	0	80	79.8	1	30	1	204
C27	30	26	26	31	27	28	28	27	29	30	29	29	28.3	1	0	80	79.8	1	29	1	198
C28	26	24	26	22	25	23	25	30	28	27	26	26	25.7	1	0	80	79.8	1	27	1	164
C29	22	24	21	25	23	24	24	23	25	26	24	24	23.8	1	0	80	79.8	1	25	1	139
C30	24	20	23	26	26	27	24	27	28	23	26	24	24.8	1	0	80	79.8	1	26	1	153
C31	21	23	20	26	22	22	25	25	24	27	24	24	23.6	1	0	80	79.8	1	25	1	136
C32	26	25	25	24	25	25	25	27	28	27	26	29	26.0	1	0	80	79.8	1	27	1	168
C33	23	23	23	23	24	26	23	25	27	23	26	26	24.3	1	0	80	79.8	1	25	1	146
C34	22	26	25	25	26	28	24	24	26	25	24	28	25.3	1	0	80	79.8	1	26	1	158
C35	21	24	24	27	26	24	25	27	26	28	29	26	25.6	1	0	80	79.8	1	27	1	162
C36	21	20	21	22	25	25	25	21	25	22	24	23	22.8	1	0	80	79.8	1	24	1	127
C37	24	25	25	26	25	26	28	24	26	24	27	26	25.5	1	0	80	79.8	1	27	1	161
C38	27	25	23	25	25	23	26	27	24	24	26	24	24.9	1	0	80	79.8	1	26	1	154
C39	22	22	24	23	22	29	24	28	25	29	30	30	25.7	1	0	80	79.8	1	27	1	164
C40	23	27	25	24	22	26	23	21	22	23	25	24	23.8	1	0	80	79.8	1	25	1	139
C41	20	21	24	24	24	22	25	22	23	23	22	26	23.0	1	0	80	79.8	1	24	1	129
C42	27	24	26	24	26	26	21	23	23	23	20	24	23.9	1	0	80	79.8	1	25	1	141
C43	20	19	21	24	22	22	23	21	25	20	26	23	22.2	1	0	80	79.8	1	23	1	118
C44	21	22	21	25	24	22	23	23	25	22	23	21	22.7	1	0	80	79.8	1	24	1	124
C45	19	22	20	23	23	26	26	25	28	23	25	21	23.4	1	0	80	79.8	1	24	1	134
C46	19	19	21	21	19	20	21	19	20	20	22	20	20.1	1	0	80	79.8	1	21	1	91
C47	21	21	23	22	23	26	25	21	26	23	25	20	23.0	1	0	80	79.8	1	24	1	129
C48	19	19	22	24	25	23	24	24	25	23	25	22	22.9	1	0	80	79.8	1	24	1	128
C49	26	27	25	25	26	28	28	27	29	25	27	25	26.5	1	0	80	79.8	1	28	1	174

Probeta N°	índice de Rebote												Promedio (Ro)	Factor de corrección por ángulo de impacto (∆R)	Factor de corrección del estado de humedad de la superficie (∆Rw)	Valor Nominal del Yunque (Ra)	Promedio (Rao)	Ra/Rao	índice de Rebote corregido (R)	Factor de corrección por edad del concreto (αn)	Resistencia a la compresión (kg/cm2)
	1	2	3	4	5	6	7	8	9	10	11	12		0	seco				R=Ro*(Ra/Rao) +∆R+∆Rw	28	F=(-184+13*R) *αn
C50	22	22	25	25	28	25	25	26	25	24	30	27	25.3	1	0	80	79.8	1	26	1	159
C51	19	24	21	22	24	26	22	23	24	27	22	21	22.9	1	0	80	79.8	1	24	1	128
C52	21	20	21	23	21	22	23	22	22	19	23	20	21.4	1	0	80	79.8	1	22	1	108
C53	19	20	19	22	23	26	24	21	26	21	20	25	22.2	1	0	80	79.8	1	23	1	118
C54	19	22	19	22	21	22	23	24	23	25	21	22	21.9	1	0	80	79.8	1	23	1	115
C55	24	24	23	26	26	29	27	29	25	26	25	27	25.9	1	0	80	79.8	1	27	1	167
C56	25	23	22	27	29	26	27	29	27	26	25	27	26.1	1	0	80	79.8	1	27	1	169
C57	25	25	24	29	28	26	25	27	24	22	26	25	25.5	1	0	80	79.8	1	27	1	161
C58	31	33	34	28	37	35	32	36	35	31	33	33	33.2	1	0	80	79.8	1	34	1	261
C59	32	30	33	33	29	31	34	32	29	34	29	30	31.3	1	0	80	79.8	1	32	1	237
C60	31	29	31	29	29	28	33	34	34	32	32	31	31.1	1	0	80	79.8	1	32	1	234
C61	26	26	22	30	23	26	28	25	30	23	25	23	25.6	1	0	80	79.8	1	27	1	162
C62	20	22	23	26	24	26	26	24	26	26	24	22	24.1	1	0	80	79.8	1	25	1	143
C63	27	22	29	26	26	28	26	25	31	25	22	25	26.0	1	0	80	79.8	1	27	1	168
C64	24	24	23	26	26	29	27	29	25	26	25	27	25.9	1	0	80	79.8	1	27	1	167
C65	25	23	22	27	29	26	27	29	27	26	25	27	26.1	1	0	80	79.8	1	27	1	169
C66	25	25	24	29	28	26	25	27	24	22	26	25	25.5	1	0	80	79.8	1	27	1	161
C67	21	25	23	27	24	24	25	23	25	24	23	25	24.1	1	0	80	79.8	1	25	1	143
C68	26	25	25	25	29	27	26	24	27	24	26	24	25.7	1	0	80	79.8	1	27	1	164
C69	23	24	22	25	23	26	26	25	26	25	26	26	24.8	1	0	80	79.8	1	26	1	152
C70	20	22	25	24	23	22	24	26	26	25	22	27	23.8	1	0	80	79.8	1	25	1	140

Fuente: Elaboración Propia

3.3.3. Análisis de Resultados

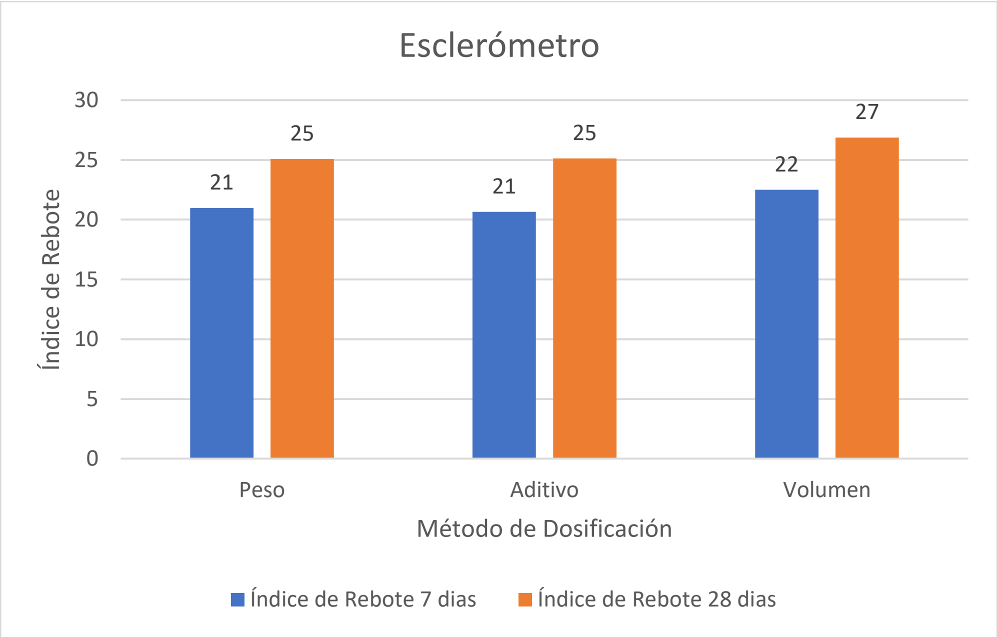
Tabla 17. Promedio de Resultados Esclerómetro

Edad	Método de Dosificación	Índice de Rebote
7	Peso	21
	Aditivo	21
	Volumen	22
28	Peso	25
	Aditivo	25
	Volumen	27

Fuente: Elaboración Propia

En la Figura 34 se observa el crecimiento progresivo de las muestras ensayadas con el esclerómetro a los 7 y 28 días, se puede observar claramente que los mejores resultados para esta son los que se presentan en el método de dosificación al volumen.

Figura 34. Análisis de Resultados Esclerómetro



Fuente: Elaboración Propia

3.3.4. Holcim (8 meses)

Tabla 18. Cálculos de Índice de Rebote Holcim

Probeta N°	Índice de Rebote												Promedio (Ro)	Factor de corrección por ángulo de impacto (∆R)	Factor de corrección del estado de humedad de la superficie (∆Rw)	Valor Nominal del Yunque (Ra)	Promedio (Rao)	Ra/Rao	Índice de Rebote corregido (R)	Factor de corrección por edad del concreto (αn)	Resistencia a la compresión (kg/cm2)
	1	2	3	4	5	6	7	8	9	10	11	12		0	seco				R=Ro*(Ra/Rao) +∆R+∆Rw	28	F=(-184+13*R) *αn
C1	33	34	35	39	32	36	37	33	37	36	35	35	35.2	1	0	80	79.8	1	36	1	287
C2	32	34	31	35	34	36	35	34	35	32	35	30	33.6	1	0	80	79.8	1	35	1	267
C3	29	24	28	29	25	30	26	29	28	27	25	24	27.0	1	0	80	79.8	1	28	1	181
C4	31	32	32	34	35	35	39	33	34	32	31	32	33.3	1	0	80	79.8	1	34	1	263
C5	32	31	32	35	34	34	35	36	34	33	31	33	33.3	1	0	80	79.8	1	34	1	263
C6	27	31	29	33	30	31	31	36	31	30	32	33	31.2	1	0	80	79.8	1	32	1	235
C7	20	22	25	24	23	22	24	26	26	25	22	27	23.8	1	0	80	79.8	1	25	1	140
C8	29	30	40	35	36	40	33	34	35	35	30	32	34.1	1	0	80	79.8	1	35	1	273
C9	26	26	24	27	30	29	31	32	32	31	31	30	29.1	1	0	80	79.8	1	30	1	208
C10	31	34	34	32	37	37	37	38	38	38	35	35	35.5	1	0	80	79.8	1	37	1	292
C11	30	31	30	34	31	33	28	29	32	28	27	33	30.5	1	0	80	79.8	1	32	1	226
C12	30	30	30	32	34	32	31	31	30	30	28	25	30.3	1	0	80	79.8	1	31	1	223
C13	30	30	31	30	33	35	32	34	32	31	31	33	31.8	1	0	80	79.8	1	33	1	244
C14	27	30	27	34	33	31	33	32	33	30	31	28	30.8	1	0	80	79.8	1	32	1	230
C15	30	31	34	36	32	36	34	33	35	30	34	35	33.3	1	0	80	79.8	1	34	1	263
C16	28	30	30	29	31	33	29	26	30	29	27	28	29.2	1	0	80	79.8	1	30	1	209
C17	25	26	26	30	30	28	27	31	31	27	28	24	27.8	1	0	80	79.8	1	29	1	191
C18	27	26	26	29	28	29	31	28	25	27	28	29	27.8	1	0	80	79.8	1	29	1	191
C19	30	29	30	27	30	31	32	32	33	31	28	27	30.0	1	0	80	79.8	1	31	1	220
C20	31	29	31	29	29	28	33	34	34	32	32	31	31.1	1	0	80	79.8	1	32	1	234

Fuente: Elaboración Propia

4. Correlaciones

En esta sección se presentan las tablas resumen donde se muestran los resultados obtenidos de cada uno de los ensayos realizados para complementar esta investigación, para a continuación modelar mediante gráficos una dispersión, permitiéndonos sacar su ecuación de tendencia y su índice de correlación (R^2), para ayudarnos así presentar las conclusiones y recomendaciones para esta investigación.

4.1. Tabla de Resumen

4.1.1. 7 días

Tabla 19. Resumen de Resultados 7 días

# Probeta	Índice de Rebote	Ultrasonido Tico	Ultrasonido Elsonic ESI/P-10	Resistencia a la compresión (Kg/cm2)
		Velocidad de Propagación de Onda (Km/s)	Velocidad de Propagación de Onda (Km/s)	
C1	21	2.65	2.51	96
C2	22	2.59	2.64	94
C3	22	2.78	2.61	100
C4	25	3.60	3.30	224
C5	24	3.76	3.38	223
C6	27	3.38	3.31	194
C7	26	3.53	3.10	175
C8	23	3.47	3.18	116
C9	24	3.28	3.08	108
C10	22	3.03	2.89	99
C11	26	3.17	2.93	118
C12	23	3.11	2.94	112
C13	25	2.90	3.24	211
C14	26	3.93	3.29	198
C15	21	2.69	3.06	130
C16	18	2.59	2.99	78
C17	21	2.73	3.04	90
C18	26	2.92	3.23	169
C19	25	2.94	3.26	182
C20	24	3.95	3.29	180
C21	27	3.17	2.83	135
C22	28	3.23	2.91	136

# Probeta	Índice de Rebote	Ultrasonido Tico	Ultrasonido Elsonic ESI/P-10	Resistencia a la compresión (Kg/cm2)
		Velocidad de Propagación de Onda (Km/s)	Velocidad de Propagación de Onda (Km/s)	
C23	35	3.57	3.20	213
C24	34	3.56	3.20	271
C25	33	3.40	3.22	233
C26	29	3.67	3.26	221
C27	31	3.54	3.16	264
C28	33	3.56	3.16	255
C29	31	3.63	3.20	273
C30	27	2.82	2.74	169
C31	28	2.86	2.66	158
C32	29	3.02	2.77	169
C33	25	3.32	2.99	133
C34	27	3.52	3.12	205
C35	28	2.45	3.04	151
C36	26	2.53	3.14	148
C37	25	2.39	3.06	127
C38	24	2.67	3.12	140
C39	22	3.71	3.36	146
C40	24	3.92	3.39	109
C41	24	2.86	3.41	150
C42	30	2.94	2.80	219
C43	30	3.05	2.82	213
C44	30	2.96	2.87	154
C45	25	3.33	2.99	170
C46	28	2.53	3.00	198
C47	30	2.41	2.98	206
C48	33	2.91	3.43	313
C49	30	3.85	3.40	331
C50	34	3.94	3.45	298
C51	32	3.30	3.21	237
C52	30	2.64	3.22	225
C53	33	3.52	3.23	212
C54	28	2.66	3.15	152
C55	29	2.70	3.19	207
C56	28	2.79	3.28	193
C57	28	2.62	3.21	189
C58	28	3.57	3.21	188
C59	24	3.55	3.16	164

# Probeta	Índice de Rebote	Ultrasonido Tico	Ultrasonido Elsonic ESI/P-10	Resistencia a la compresión (Kg/cm2)
		Velocidad de Propagación de Onda (Km/s)	Velocidad de Propagación de Onda (Km/s)	
C60	26	3.13	3.06	176
C61	26	3.17	3.01	161
C62	24	3.26	3.02	161
C63	25	3.39	3.02	176
C64	25	3.25	3.08	165
C65	29	3.16	3.03	172
C66	28	3.42	3.12	176
C67	22	3.09	3.01	82
C68	21	3.19	3.05	84
C69	23	3.24	2.94	85
C70	20	3.07	2.99	82

Fuente: Elaboración Propia

4.1.2. 28 días

Tabla 20. Resumen de Resultados 28 días

# Probeta	Índice de Rebote	Ultrasonido Tico	Ultrasonido Elsonic ESI/P-10	Resistencia a la compresión (Kg/cm2)
		Velocidad de Propagación de Onda (Km/s)	Velocidad de Propagación de Onda (Km/s)	
C1	21	2.99	2.78	159
C2	21	3.12	2.80	145
C3	22	2.94	2.75	152
C4	24	2.79	3.19	232
C5	24	2.58	3.05	209
C6	24	3.65	3.28	200
C7	27	3.40	3.47	339
C8	27	3.27	3.40	315
C9	31	2.95	3.47	350
C10	27	3.86	3.31	260
C11	29	3.73	3.35	282
C12	23	3.90	3.40	204
C13	24	3.50	3.14	185
C14	24	3.47	3.19	182
C15	25	3.52	3.19	189
C16	23	3.44	3.13	161
C17	24	3.63	3.19	164
C18	23	3.72	3.17	178
C19	24	3.80	3.32	196
C20	25	4.06	3.50	214
C21	24	3.95	3.42	207
C22	26	3.24	3.08	179
C23	25	3.33	3.08	189
C24	23	3.51	3.13	207
C25	28	3.92	3.40	298
C26	30	3.75	3.38	300
C27	29	3.92	3.41	329
C28	27	3.11	2.89	293
C29	25	2.98	2.73	249
C30	26	3.15	2.88	281
C31	25	3.20	3.37	220
C32	27	2.71	3.28	269
C33	25	2.77	3.21	213
C34	26	3.42	3.47	233

# Probeta	Índice de Rebote	Ultrasonido Tico	Ultrasonido Elsonic ESI/P-10	Resistencia a la compresión (Kg/cm2)
		Velocidad de Propagación de Onda (Km/s)	Velocidad de Propagación de Onda (Km/s)	
C35	27	3.96	3.44	214
C36	24	3.88	3.48	191
C37	27	2.89	3.17	199
C38	26	3.76	3.26	227
C39	27	3.60	3.14	283
C40	25	3.48	3.18	244
C41	24	3.66	3.22	244
C42	25	3.76	3.19	265
C43	23	3.70	3.27	180
C44	24	3.59	3.29	180
C45	24	3.75	3.29	203
C46	21	3.71	3.04	168
C47	24	3.59	3.28	208
C48	24	3.74	3.05	154
C49	28	2.97	3.30	275
C50	26	3.92	3.23	202
C51	24	2.69	3.07	141
C52	22	2.93	2.65	219
C53	23	2.86	2.62	213
C54	23	2.87	2.71	154
C55	27	3.91	3.28	281
C56	27	3.95	3.27	290
C57	27	3.97	3.36	284
C58	34	4.06	3.48	427
C59	32	4.07	3.49	418
C60	32	4.23	3.55	435
C61	27	3.83	3.35	280
C62	25	3.71	3.29	269
C63	27	3.78	3.36	280
C64	27	3.91	3.28	278
C65	27	3.95	3.27	291
C66	27	3.97	3.36	274
C67	25	4.12	3.41	281
C68	27	3.91	3.31	274
C69	26	4.21	3.42	254
C70	25	4.02	3.35	282

Fuente: Elaboración Propia

4.1.3. Holcim

Tabla 21. Resumen de Resultados Holcim

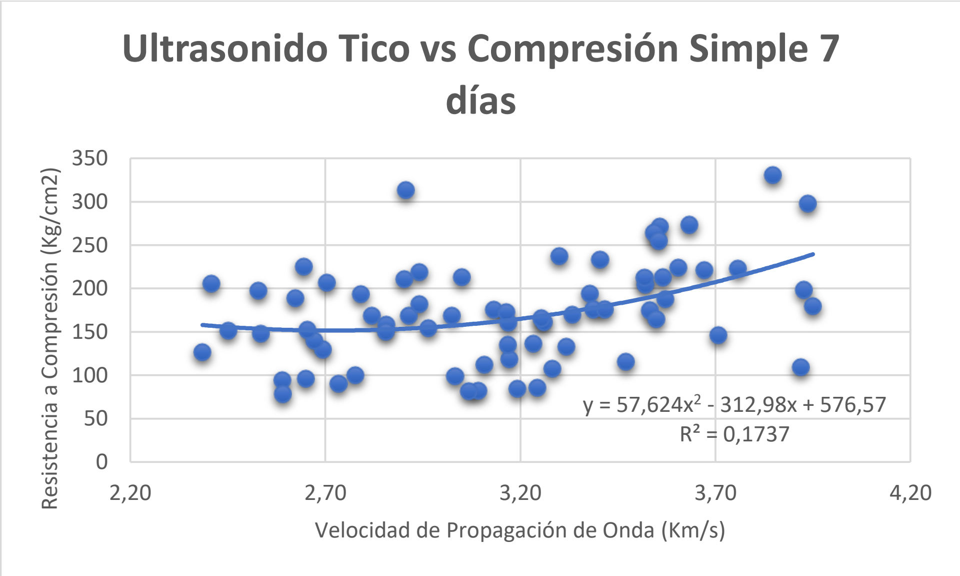
# Probeta	Índice de Rebote	Ultrasonido Tico	Ultrasonido Elsonic ESI/P-10	Resistencia a la compresión (Kg/cm2)
		Velocidad de Propagación de Onda (Km/s)	Velocidad de propagación de Onda (Km/s)	
C1	36	4.16	3.53	639
C2	35	3.96	3.53	622
C3	28	2.96	3.33	357
C4	34	4.26	3.55	573
C5	34	4.05	3.48	509
C6	32	4.38	3.48	510
C7	25	4.02	3.35	282
C8	35	4.45	3.58	509
C9	30	4.45	3.56	461
C10	37	4.34	3.59	746
C11	32	4.25	3.55	463
C12	31	4.26	3.49	518
C13	33	4.28	3.51	495
C14	32	4.26	3.46	552
C15	34	4.35	3.54	517
C16	30	4.28	3.47	504
C17	29	4.31	3.47	382
C18	29	4.25	3.44	444
C19	31	3.13	2.66	378
C20	32	4.23	3.55	435

Fuente: Elaboración Propia

4.2. Ultrasonido Tico vs Compresión Simple

4.2.1. 7 días

Figura 35. Ultrasonido Tico vs Compresión Simple 7 días



Fuente: Elaboración Propia

Para el hormigón ensayado a los 7 días de edad, con un número de muestras de 70, se observó que la mejor correlación de resultados entre la compresión simple y velocidad de propagación de onda medido con el ultrasonido Tico es de forma polinómica como se muestra en la figura 18. Se observa una gráfica dispersa con un coeficiente de determinación $R^2 = 0.1737$, representado en la siguiente fórmula:

$$y = 57.624x^2 - 312.98x + 576.57$$

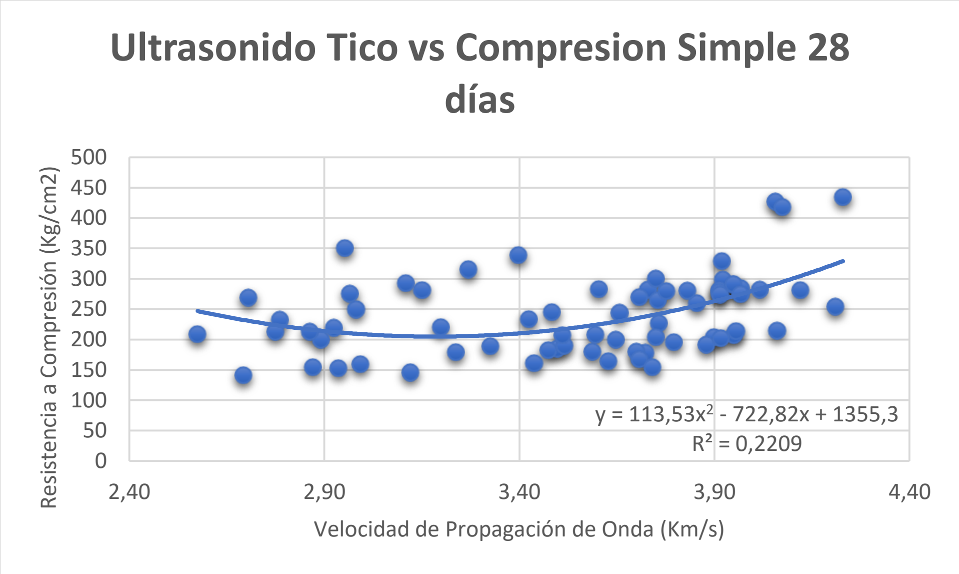
Donde:

y: Resistencia a la compresión (kg/cm2)

x: Valor de velocidad de propagación de Onda medido (km/s)

4.2.2. 28 días

Figura 36. Ultrasonido Tico vs Compresión Simple 28 días



Fuente: Elaboración Propia

Para el hormigón ensayado a los 28 días de edad, con un número de muestras de 70, se observó que la mejor correlación de resultados entre la compresión simple y velocidad de propagación de onda medido con el ultrasonido Tico es de forma polinómica como se muestra en la figura 19. Cabe mencionar que existe una mejora en los resultados mostrándonos comparados con los resultados a los 7 días. Se observa una gráfica dispersa con un coeficiente de determinación $R^2 = 0.2209$, representado en la siguiente fórmula:

$$y = 113.53x^2 - 722.82x + 1355.3$$

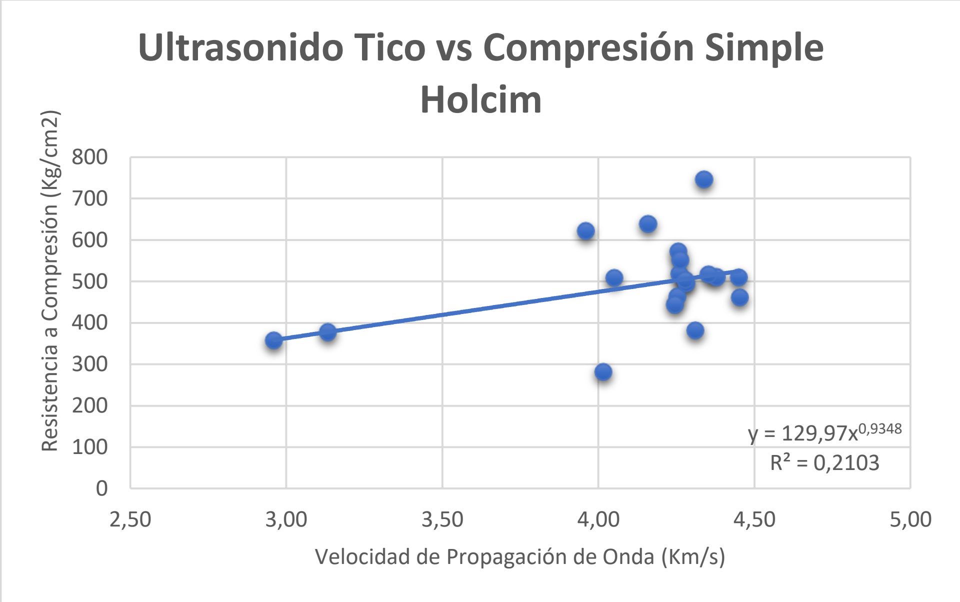
Donde:

y: Resistencia a la compresión (kg/cm2)

x: Valor de velocidad de propagación de Onda medido (km/s)

4.2.3. Holcim

Figura 37. Ultrasonido Tico vs Compresión Simple Holcim



Fuente: Elaboración Propia

Para los cilindros proporcionados por la hormigonera Holcim, con un número de muestras de 20, se observó que la mejor correlación de resultados entre la compresión simple y velocidad de propagación de onda medidos con el ultrasonido Tico es de forma potencial como se muestra en la figura 20. Cabe mencionar que existe una mejora en los resultados comparado con la línea de tendencia a los 7 días y muy próxima a la tendencia de los 28 días. Se observa una gráfica dispersa a pesar de su gran control de calidad, con un coeficiente de determinación $R^2 = 0.2103$, representado en la siguiente fórmula:

$$y = 113.53x^{0.9348}$$

Donde:

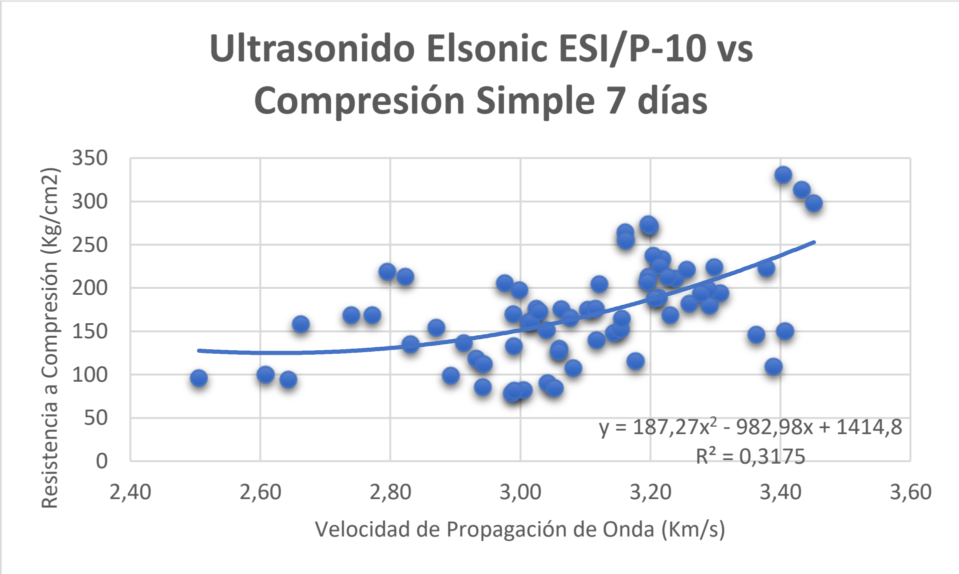
y: Resistencia a la compresión (kg/cm2)

x: Valor de velocidad de propagación de Onda medido (km/s)

4.3. Ultrasonido Elsonic ESI/P-10 vs Compresión Simple

4.3.1. 7 días

Figura 38. Ultrasonido Elsonic ESI/P-10 vs Compresión Simple 7 días



Fuente: Elaboración Propia

Para el mismo hormigón ensayado con el ultrasonido tico a los 7 días se evaluó con el ultrasonido Elsonic ESI/P-10, obteniendo como el mejor resultado de correlación entre la compresión simple y los resultados de velocidad de propagación de onda medido por el ultrasonido Elsonic ESI/P10, es de forma polinómica como se presenta en la Figura 21, se observa que a diferencia del otro ultrasonido se obtiene una mejora considerable a los 7 días con respecto a los resultados presentados anteriormente, gráficamente se observa una gráfica menos dispersa con un coeficiente de determinación $R^2 = 0.3175$, representado en la siguiente fórmula:

$$y = 187.27x^2 - 982.98x + 1414.8$$

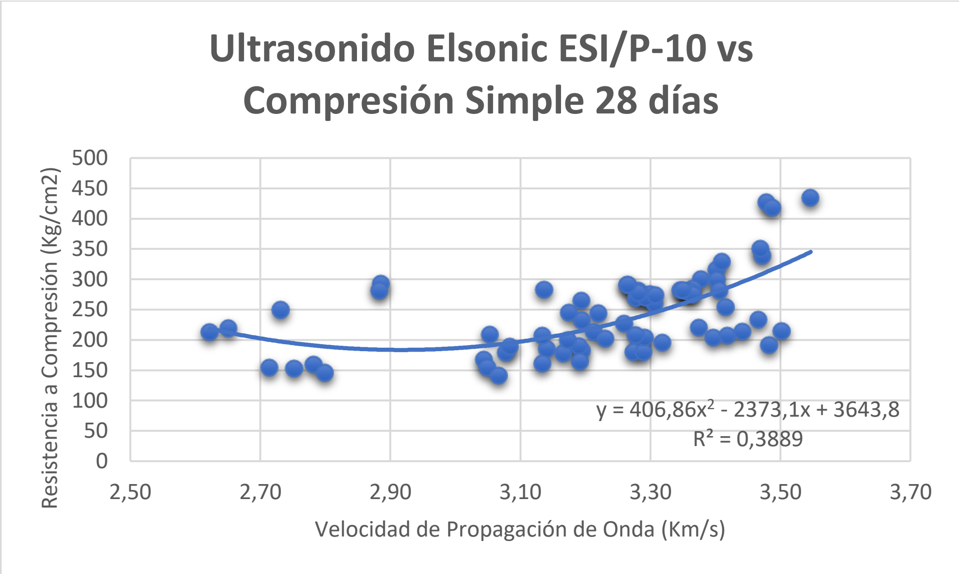
Donde:

y: Resistencia a la compresión (kg/cm2)

x: Valor de velocidad de propagación de Onda medido (km/s)

4.3.2. 28 días

Figura 39. Ultrasonido Elsonic ESI/P-10 vs Compresión Simple 28 días



Fuente: Elaboración Propia

Para el mismo hormigón ensayado con el ultrasonido tico a los 28 días se evaluó con el ultrasonido Elsonic ESI/P-10, obteniendo como el mejor resultado de correlación entre la compresión simple y los resultados de velocidad de propagación de onda medido por el ultrasonido Elsonic ESI/P-10, es de forma polinómica como se presenta en la Figura 22, se observa que a diferencia del otro ultrasonido se obtiene una mejora considerable a los 28 días con respecto a los resultados presentados anteriormente y una mejora con los resultados presentados en la gráfica de 7 días de este mismo ultrasonido, gráficamente se observa una menor dispersión con un coeficiente de determinación $R^2 = 0.3889$, representado en la siguiente fórmula:

$$y = 406.86x^2 - 2373.1x + 3643.8$$

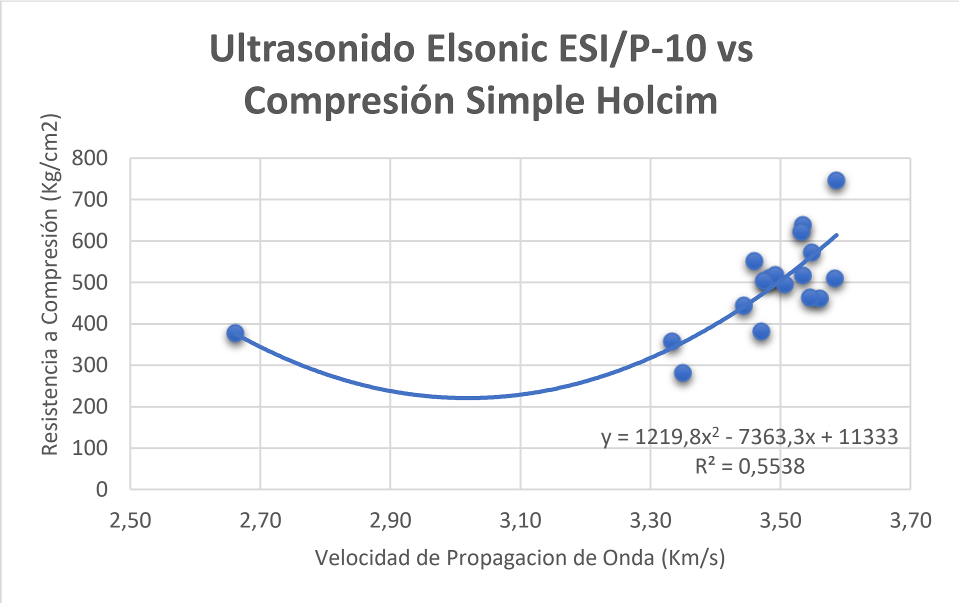
Donde:

y: Resistencia a la compresión (kg/cm2)

x: Valor de velocidad de propagación de Onda medido (km/s)

4.3.3. Holcim

Figura 40. Ultrasonido Elsonic ESI/P-10 vs Compresión Simple Holcim



Fuente: Elaboración Propia

Para los cilindros obtenidos de la hormigonera Holcim, se le hizo el mismo ensayo que con el ultrasonido Tico, pero con el ultrasonido Elsonic ESI/P-10, obteniendo como el mejor resultado de correlación entre la compresión simple y la velocidad de propagación medida por el ultrasonido Elsonic ESI/P-10, es de forma polinómica como se presenta en la Figura 23, se observa que este es el mejor de los resultados anteriormente presentados, dándonos el mejor índice de determinación con valor $R^2 = 0.5538$, representado gráficamente mediante la siguiente ecuación:

$$y = 1219.8x^2 - 7363.3x + 11333$$

Donde:

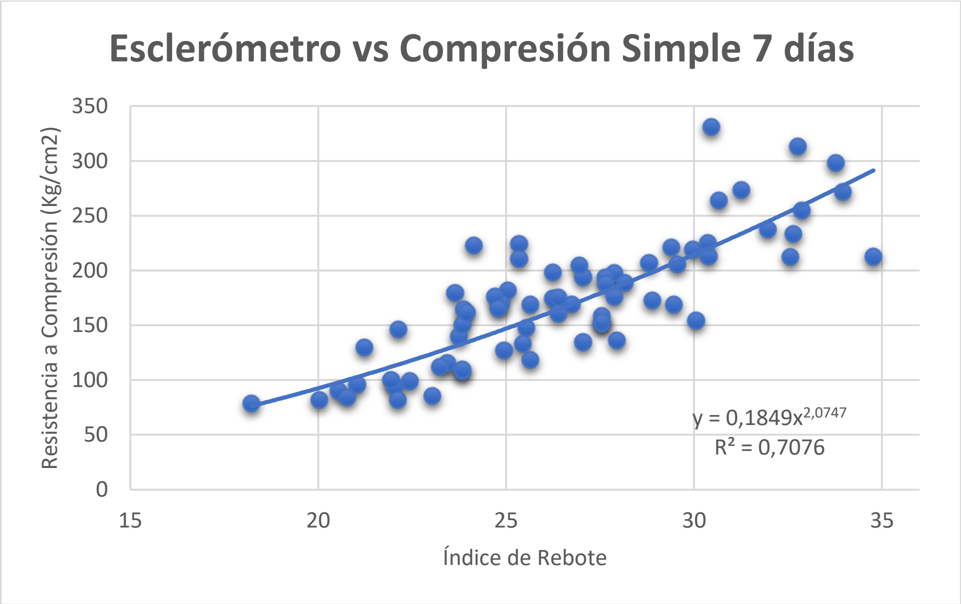
y: Resistencia a la compresión (kg/cm2)

x: Valor de velocidad de propagación de Onda medido (km/s)

4.4. Esclerómetro vs Compresión Simple

4.4.1. 7 días

Figura 41. Esclerómetro vs Compresión Simple 7 días



Fuente: Elaboración Propia

Para el hormigón evaluado a los 7 días de edad, la correlación que obtuvo el mejor de resultado entre la compresión simple y el índice de rebote, es de forma potencial tal como se la presenta en la Figura 24, gráficamente se observa una tendencia marcada con poca dispersión, dándonos como resultado un índice de determinación $R^2 = 0.7076$, representada con la siguiente fórmula:

$$y = 0.1849x^{2.0747}$$

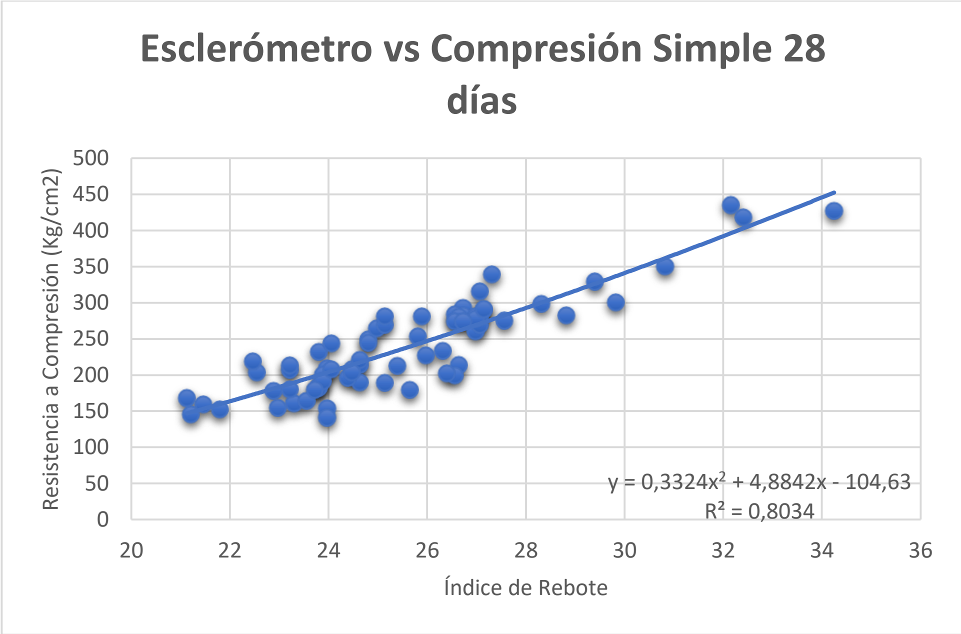
Donde:

y: Resistencia a la compresión (kg/cm2)

x: Valor de índice de rebote medido

4.4.2. 28 días

Figura 42. Esclerómetro vs Compresión Simple 28 días



Fuente: Elaboración Propia

Para el hormigón evaluado a los 28 días de edad, la correlación que obtuvo el mejor de resultado entre la compresión simple y el índice de rebote, es de forma polinómica tal como se la presenta en la Figura 25, gráficamente se observa una tendencia marcada, adicionalmente se observa que el valor de R^2 ha mejorado notablemente con respecto a los resultados a los 7 días mostrados en la Figura 24, dándonos como resultado un índice de determinación $R^2 = 0.8034$, representada con la siguiente fórmula:

$$y = 0.3324x^2 + 4.8842x - 104.63$$

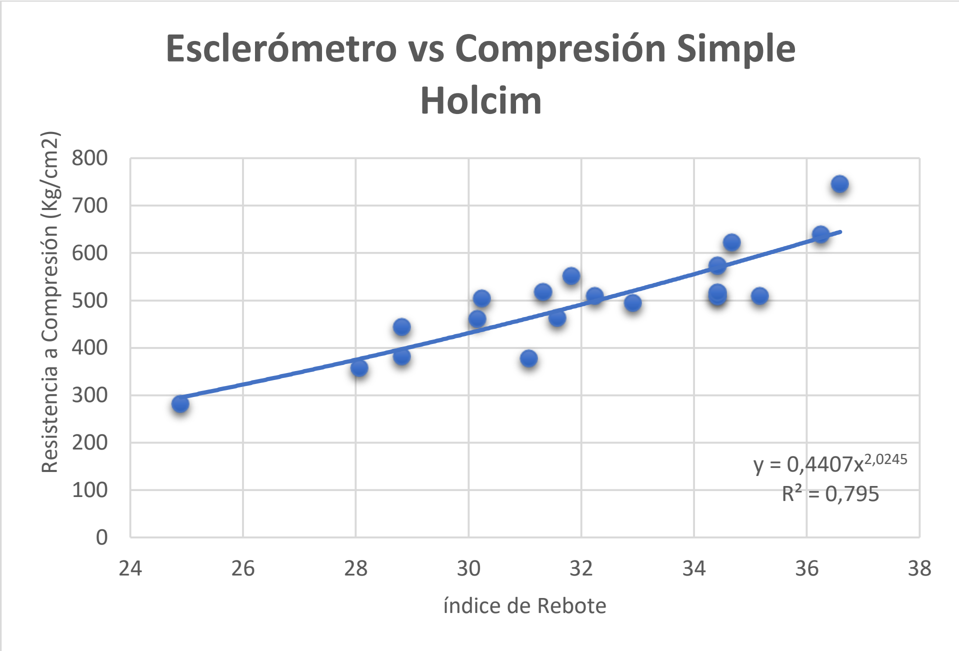
Donde:

y: Resistencia a la compresión (kg/cm2)

x: Valor de índice de rebote medido

4.4.3. Holcim

Figura 43. Esclerómetro vs Compresión Simple Holcim



Fuente: Elaboración Propia

Para los cilindros proporcionados por la hormigonera Holcim, la correlación que obtuvo el mejor de resultado entre la compresión simple y el índice de rebote, es de forma potencial tal como se la presenta en la Figura 26, gráficamente se observa una tendencia marcada con menor número de muestras, adicionalmente se observa que el valor de R^2 ha mejorado notablemente con respecto a los resultados a los 7 días y esta próximo al valor de los 28 días mostrados en la Figura 24 y 25, dándonos como resultado un índice de determinación $R^2 = 0.795$, representada con la siguiente fórmula:

$$y = 0.4407x^{2.0245}$$

Donde:

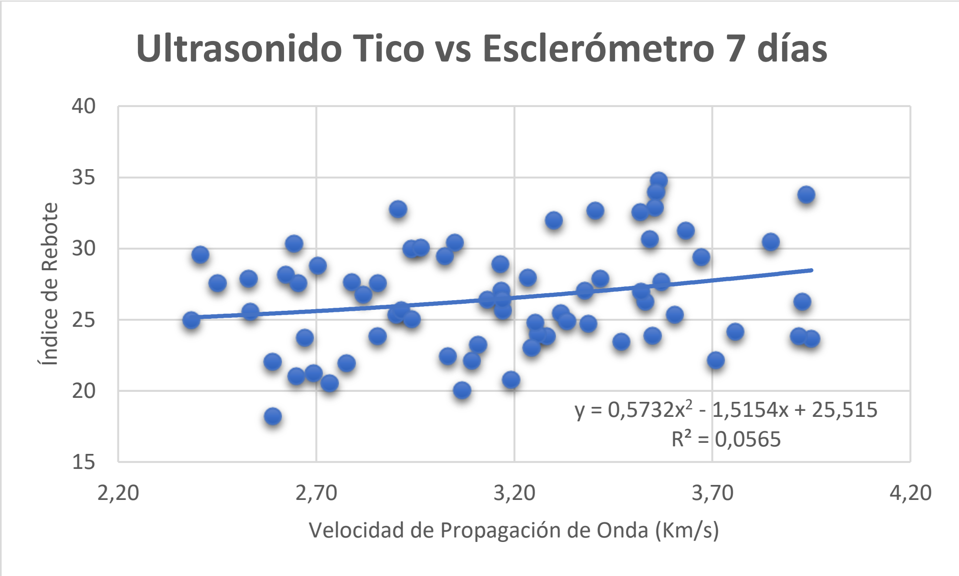
y: Resistencia a la compresión (kg/cm2)

x: Valor de índice de rebote medido

4.5. Ultrasonido Tico vs Esclerómetro

4.5.1. 7 días

Figura 44. Ultrasonido Tico vs Esclerómetro 7 días



Fuente: Elaboración Propia

Para el hormigón ensayado a los 7 días de edad, con un numero de muestras de 70, se observó que la mejor correlación de resultados entre el índice de rebote y velocidad de propagación de onda medido con el ultrasonido Tico es de forma polinómica como se muestra en la figura 27, se observa una gráfica totalmente dispersa con un coeficiente de determinación bajo $R^2 = 0.0565$, representado en la siguiente fórmula:

$$y = 0.5732x^2 - 1.5154x + 25.515$$

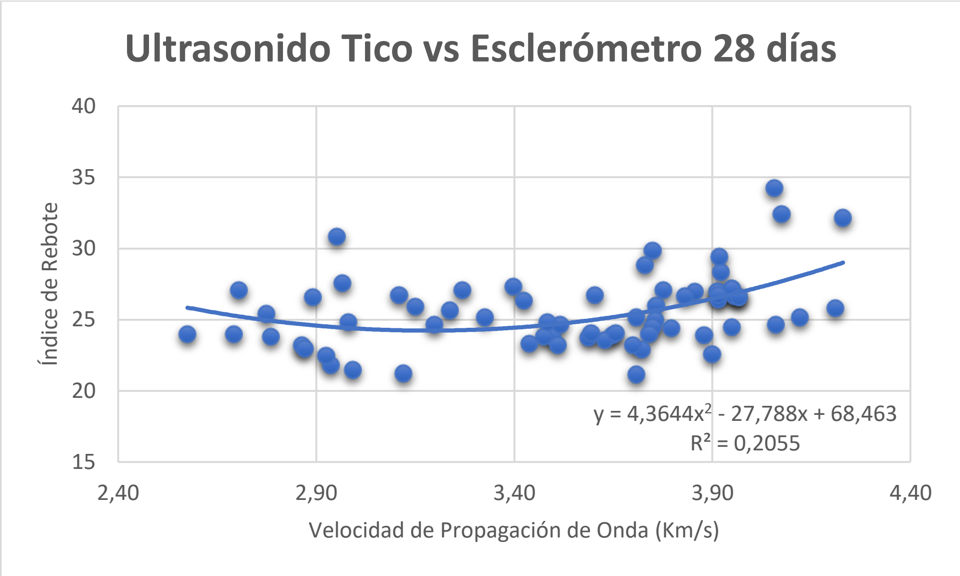
Donde:

y: Índice de rebote

x: Valor de velocidad de propagación de Onda medido (km/s)

4.5.2. 28 días

Figura 45. Ultrasonido Tico vs Esclerómetro 28 días



Fuente: Elaboración Propia

Para el hormigón ensayado a los 28 días de edad, con un numero de muestras de 70, se observó que la mejor correlación de resultados entre el índice de rebote y velocidad de propagación de onda medido con el ultrasonido Tico, es de forma polinómica como se muestra en la Figura 28, cabe mencionar que existe una mejora en los resultados mostrándonos una mejor tendencia que a los 7 días, se observa una gráfica menos dispersa con un coeficiente de determinación $R^2 = 0.2055$, representado en la siguiente fórmula:

$$y = 4.3644x^2 - 27.788x + 68.463$$

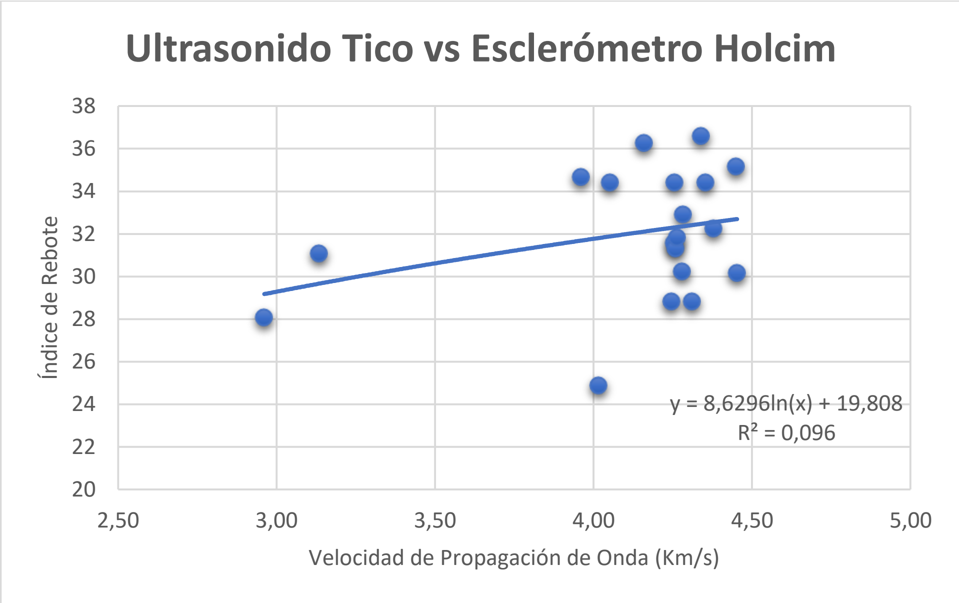
Donde:

y: Índice de rebote

x: Valor de velocidad de propagación de Onda medido (km/s)

4.5.3. Holcim

Figura 46. Ultrasonido Tico vs Esclerómetro Holcim



Fuente: Elaboración Propia

Para los cilindros proporcionados por la hormigonera Holcim, con un número de muestras de 20, se observó que la mejor correlación de resultados entre el índice de rebote y velocidad de propagación de onda medido con el ultrasonido Tico es de forma logarítmica como se muestra en la figura 29, cabe mencionar que existe una mejora en los resultados comparado con la tendencia de los 7 días y menor a la tendencia presentada a los 28 días, se observa una gráfica muy dispersa a pesar de su gran control de calidad, con un coeficiente de determinación $R^2 = 0.096$, representado en la siguiente fórmula:

$$y = 8.6296\ln(x) + 19.808$$

Donde:

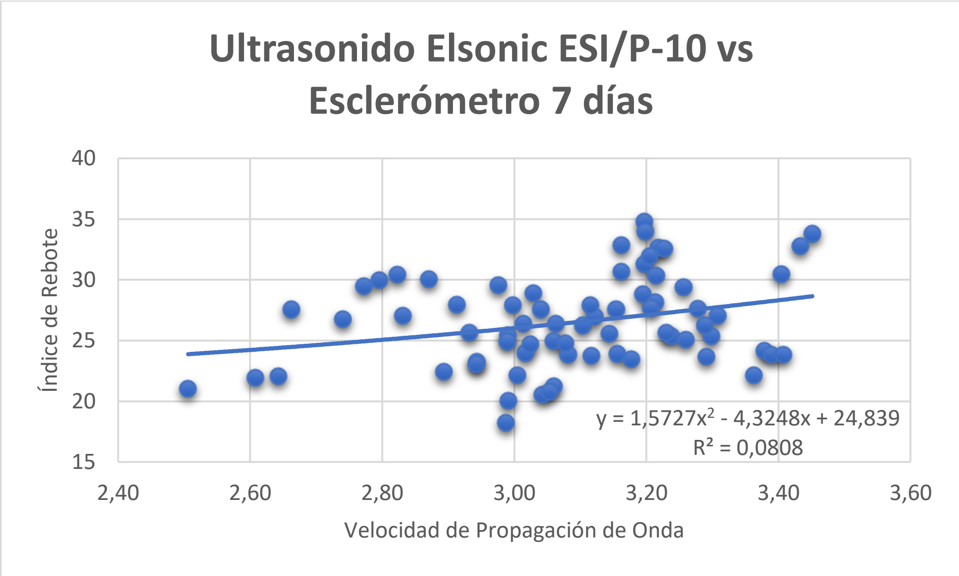
y: Índice de rebote

x: Valor de velocidad de propagación de Onda medido (km/s)

4.6. Ultrasonido Elsonic ESI/P-10 vs Esclerómetro

4.6.1. 7 días

Figura 47. Ultrasonido Elsonic ESI/P-10 vs Esclerómetro 7 días



Fuente: Elaboración Propia

Para el mismo hormigón ensayado con el ultrasonido tico a los 7 días se evaluó con el ultrasonido Elsonic ESI/P-10, obteniendo como el mejor resultado de correlación entre el índice de rebote y los resultados de velocidad de propagación de onda medido por el ultrasonido Elsonic ESI/P10, es de forma polinómica como se presenta en la Figura 30, se observa que a diferencia del otro ultrasonido se obtiene una mejora a los 7 días con respecto a los resultados presentados anteriormente, gráficamente se observa una gráfica muy dispersa con un coeficiente de determinación $R^2 = 0.0808$, representado en la siguiente fórmula:

$$y = 1.5727x^2 - 4.3248x + 24.839$$

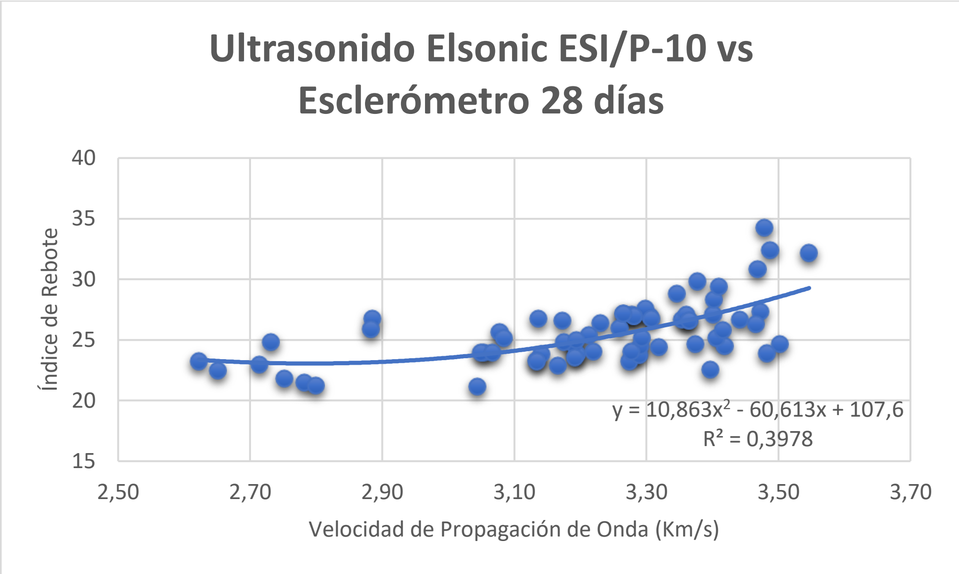
Donde:

y: Índice de rebote

x: Valor de velocidad de propagación de Onda medido (km/s)

4.6.2. 28 días

Figura 48. Ultrasonido Elsonic ESI/P-10 vs Esclerómetro 28 días



Fuente: Elaboración Propia

Para el mismo hormigón ensayado con el ultrasonido tico a los 28 días se evaluó con el ultrasonido Elsonic ESI/P-10, obteniendo como el mejor resultado de correlación entre el índice de rebote y los resultados de velocidad de propagación de onda medido por el ultrasonido Elsonic ESI/P-10, es de forma polinómica como se presenta en la Figura 31, se observa que a diferencia del otro ultrasonido se obtiene una mejora considerable a los 28 días con respecto a los resultados presentados anteriormente y una mejora con los resultados presentados en la gráfica de 7 días de este mismo ultrasonido, gráficamente se observa una gráfica menos dispersa con un coeficiente de determinación $R^2 = 0.3978$, representado en la siguiente fórmula:

$$y = 10.863x^2 - 60.613x + 107.6$$

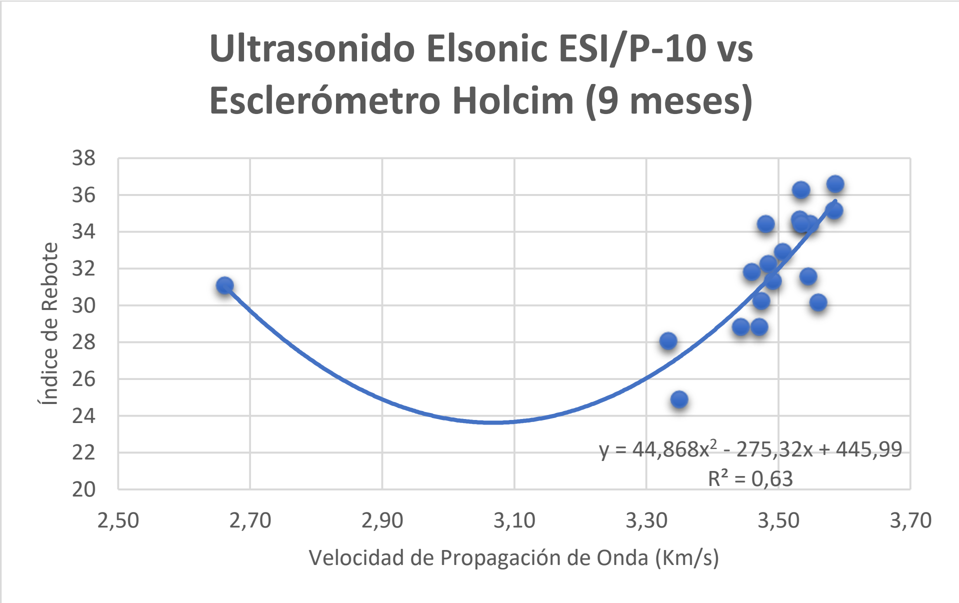
Donde:

y: Índice de rebote

x: Valor de velocidad de propagación de Onda medido (km/s)

4.6.3. Holcim

Figura 49. Ultrasonido Elsonic ESI/P-10 vs Esclerómetro Holcim



Fuente: Elaboración Propia

Para los cilindros obtenidos de la hormigonera Holcim, se le hizo el mismo ensayo que con el ultrasonido Tico, pero con el ultrasonido Elsonic ESI/P-10, obteniendo como el mejor resultado de correlación entre el índice de rebote y la velocidad de propagación medida por el ultrasonido Elsonic ESI/P-10, es de forma polinómica como se presenta en la Figura 32, se observa que este es el mejor de los resultados anteriormente presentados, dándonos el mejor índice de determinación con valor $R^2 = 0.63$, representado gráficamente mediante la siguiente ecuación:

$$y = 44.868x^2 - 275.32x + 445.99$$

Donde:

y: Índice de rebote

x: Valor de velocidad de propagación de Onda medido (km/s)

4.7. Rangos de relación y calidad de las correlaciones

A continuación, en la Tabla 20, se muestran los valores de correlación R^2 y R para cada uno de los casos analizados en este proyecto de investigación realizados mediante los parámetros indicados en las tablas 18 y 19, las cuales nos permiten clasificar la calidad de la correlación y el rango de relación permitiéndonos de esta manera realizar las conclusiones.

Tabla 22. Calidad de Correlación

R	Calidad
1	Perfecta
0.9 - 1	Excelente
0.8 - 0.9	Buena
0.5 - 0.8	Regular
<0.5	Mala

Fuente: Martínez, Tuya, Martínez, Pérez, & Cánovas, 2009

Tabla 23. Rango de Relación

R	Rango de Relación
0 - 0.25	Escasa o Nula
0.26 - 0.5	Débil
0.51 - 0.75	Moderada - Fuerte
0.76 - 1	Fuerte - Perfecta

Fuente: Martínez, Tuya, Martínez, Pérez, & Cánovas, 2009

Tabla 24. Nivel de Calidad de Correlaciones

Nombre	Edad (Días)	R^2	R	Calidad	Rango de Relación
Esclerómetro vs Compresión Simple	7	0.71	0.84	Buena	Fuerte – Perfecta
	28	0.80	0.90	Buena	Fuerte – Perfecta
	Holcim (9 meses)	0.80	0.89	Buena	Fuerte – Perfecta
Ultrasonido Tico vs Compresión Simple	7	0.17	0.42	Mala	Débil
	28	0.22	0.47	Mala	Débil
	Holcim (9 meses)	0.21	0.46	Mala	Débil
Ultrasonido Elsonic ESI/P-10 vs Compresión Simple	7	0.32	0.56	Regular	Moderada – Fuerte
	28	0.39	0.62	Regular	Moderada – Fuerte
	Holcim (9 meses)	0.55	0.74	Regular	Moderada – Fuerte
Esclerómetro vs Ultrasonido Tico	7	0.06	0.24	Mala	Escasa o Nula
	28	0.21	0.45	Mala	Débil
	Holcim (9 meses)	0.10	0.31	Mala	Débil
Esclerómetro vs Ultrasonido Elsonic ESI/P-10	7	0.08	0.28	Mala	Débil
	28	0.40	0.63	Regular	Moderada – Fuerte
	Holcim (9 meses)	0.63	0.79	Regular	Fuerte – Perfecta

Fuente: Elaboración Propia

5. Comparación del Ensayo de Resistencia a la Compresión Simple y la Resistencia Obtenida a Través de la Correlación

A continuación, se presenta una comparación de los resultados obtenidos del ensayo de resistencia a la compresión simple, y el valor obtenido a partir de las ecuaciones establecidas en el método de correlación, teniendo en cuenta el coeficiente de determinación más cercano a 1.

Tabla 25. Comparación de resultados del concreto ensayado a los 7 días

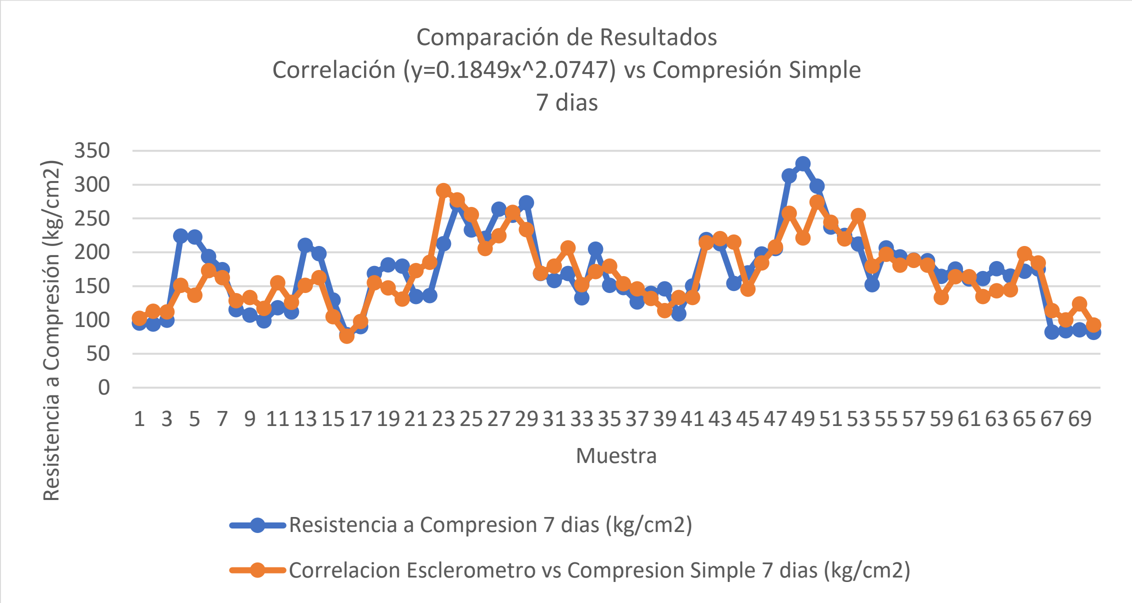
Numero de Muestra	Resistencia (Kg/cm2)	Correlación Esclerómetro vs Compresión Simple 7 días (kg/cm2)	Correlación Ultrasonido Elsonic ESI/P-10 vs Compresión Simple 7 días (kg/cm2)
1	96	103	128
2	94	113	125
3	100	112	125
4	224	151	210
5	223	137	231
6	194	173	212
7	175	163	168
8	116	129	182
9	108	133	164
10	99	117	138
11	118	155	143
12	112	126	144
13	211	151	195
14	198	163	208
15	130	105	160
16	78	76	150
17	90	98	158
18	169	155	194
19	182	148	201
20	180	131	208
21	135	173	133
22	136	185	140
23	213	291	186
24	271	278	187
25	233	256	191
26	221	206	200
27	264	224	179
28	255	259	179
29	273	234	186
30	169	169	127
31	158	180	125
32	169	207	129
33	133	152	150
34	205	172	171
35	151	180	157
36	148	154	175
37	127	146	160
38	140	132	170
39	146	114	227

Numero de Muestra	Resistencia (Kg/cm2)	Correlación Esclerómetro vs Compresión Simple 7 días (kg/cm2)	Correlación Ultrasonido Elsonic ESI/P-10 vs Compresión Simple 7 días (kg/cm2)
40	109	133	234
41	150	133	240
42	219	214	130
43	213	220	132
44	154	215	136
45	170	146	150
46	198	184	151
47	206	208	148
48	313	258	247
49	331	221	239
50	298	274	253
51	237	245	188
52	225	220	190
53	212	254	193
54	152	180	177
55	207	197	186
56	193	181	205
57	189	188	190
58	188	181	188
59	164	134	178
60	176	164	161
61	161	164	153
62	161	135	154
63	176	144	155
64	165	145	163
65	172	198	156
66	176	184	170
67	82	114	152
68	84	100	159
69	85	124	144
70	82	93	150

Fuente: Elaboración Propia

- Para el concreto ensayado a los 7 días, se presenta una ecuación potencial $y = 0.1849 * x^{2.0747}$ y un índice de determinación R^2=0.7076, donde "x" es el valor de índice de rebote, se presenta su relación entre datos en la Tabla 25 y Figura 50 a continuación:

Figura 50. Comparación de Resultados entre la Correlación (y=0.1849x^2.0747) vs Compresión Simple 7 días

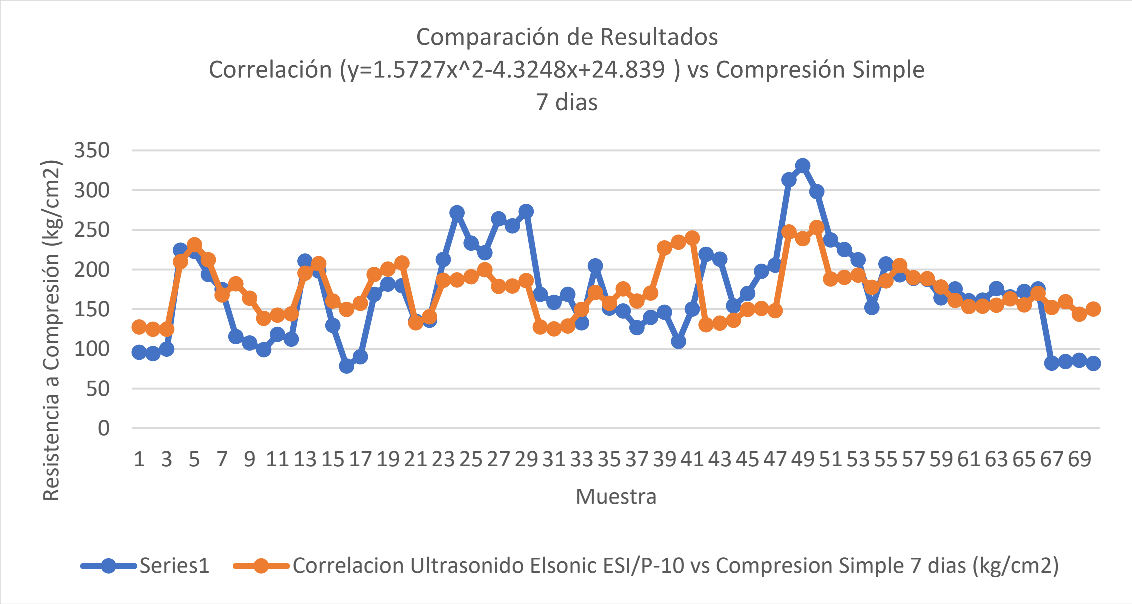


Fuente: Elaboración Propia

En la Figura 50 se muestra que los valores son semejantes con una tendencia marcada, pero también se observa que existe variación en los datos, a pesar de esto sus datos se encuentran muy cercanos a los reales por lo tanto esta ecuación se considera recomendable su uso para determinar la resistencia a compresión simple con los valores dados por el ensayo del esclerómetro para el tipo de hormigones presentados en este trabajo de investigación.

- Para el concreto ensayado a los 7 días, se presenta una ecuación polinomial $y = 187.27x^2 - 982.98x + 1414.8$ y un índice de determinación R^2=0.3175, donde "x" es el valor de la velocidad de propagación de onda, se presenta su relación entre datos en la Tabla 25 y Figura 51 a continuación:

Figura 51. Comparación de Resultados entre la Correlación (y=187.27x^2-982.98x+1414.8) vs Compresión Simple 7 días



Fuente: Elaboración Propia

En la Figura 51 se muestra que los valores son semejantes con una tendencia menos marcada, pero también se observa que existe variación más amplia en los datos, a pesar de esto sus datos se encuentran cercanos a los reales por lo tanto esta ecuación se considera recomendable su uso para determinar la resistencia a compresión simple con los valores dados por el ensayo de ultrasonido para el tipo de hormigones presentados en este trabajo de investigación.

Tabla 26. Comparación de resultados del concreto ensayado a los 28 días

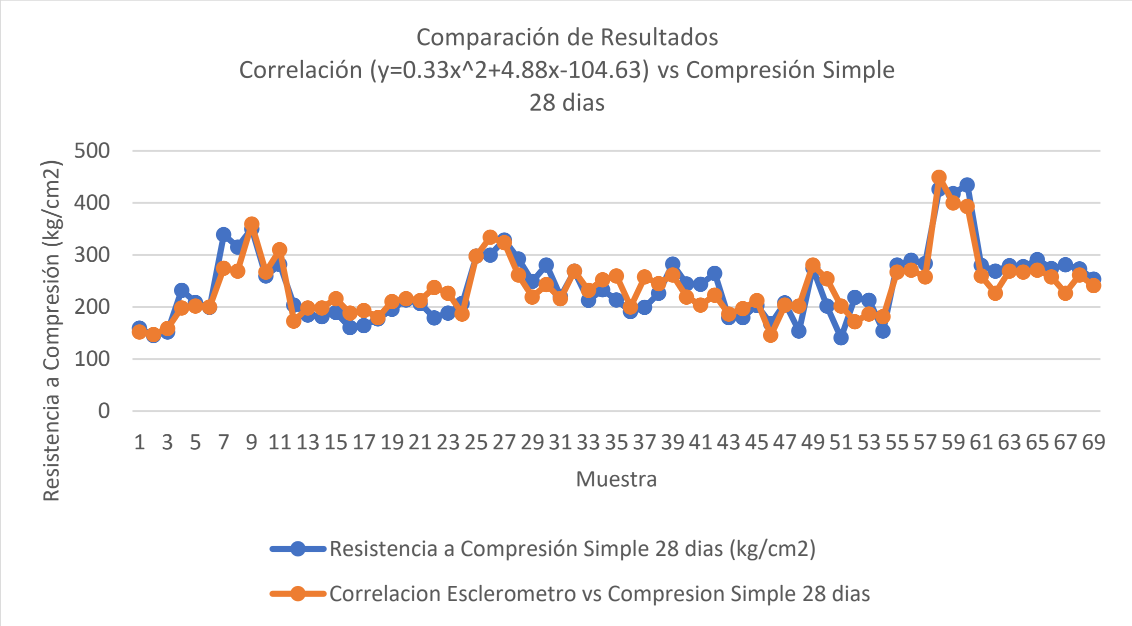
Numero de Muestra	Resistencia (Kg/cm2)	Correlación Esclerómetro vs Compresión Simple 28 días (kg/cm2)	Correlación Ultrasonido Elsonic ESI/P-10 vs Compresión Simple 28 días (kg/cm2)
1	159	152	191
2	145	147	189
3	152	159	194
4	232	199	214
5	209	202	191
6	200	200	238
7	339	275	309
8	315	269	278
9	350	359	307
10	260	267	245
11	282	310	258
12	204	173	277
13	185	199	204
14	182	199	214
15	189	216	213
16	161	188	202
17	164	193	214
18	178	180	208
19	196	211	249
20	214	216	322
21	207	212	285
22	179	238	194
23	189	227	194
24	207	187	202
25	298	298	279
26	300	334	269
27	329	324	282
28	293	262	184
29	249	220	197
30	281	243	184
31	220	216	268
32	269	269	236
33	213	232	219
34	233	252	306
35	214	260	295
36	191	200	313
37	199	258	210
38	227	245	231
39	283	262	203

Numero de Muestra	Resistencia (Kg/cm2)	Correlación Esclerómetro vs Compresión Simple 28 días (kg/cm2)	Correlación Ultrasonido Elsonic ESI/P-10 vs Compresión Simple 28 días (kg/cm2)
40	244	220	210
41	244	204	220
42	265	223	214
43	180	187	235
44	180	197	239
45	203	212	240
46	168	146	190
47	208	204	236
48	154	202	190
49	275	281	242
50	202	254	223
51	141	202	192
52	219	172	212
53	213	187	219
54	154	182	200
55	281	267	237
56	290	271	232
57	284	258	265
58	427	450	311
59	418	400	315
60	435	394	344
61	280	260	261
62	269	227	241
63	280	269	263
64	278	267	237
65	291	271	232
66	274	258	265
67	281	227	280
68	274	262	245
69	254	241	284

Fuente: Elaboración Propia

- Para el concreto ensayado a los 28 días, se presenta una ecuación polinomial $y = 0.33x^2 + 4.88x - 104.63$ y un índice de determinación R^2=0.8, donde "x" es el valor del índice de rebote, se presenta su relación entre datos en la Tabla 26 y Figura 52 a continuación:

Figura 52. Comparación de Resultados entre la Correlación (y=0.33x^2+4.88x-104.63) vs Compresión Simple 28 días

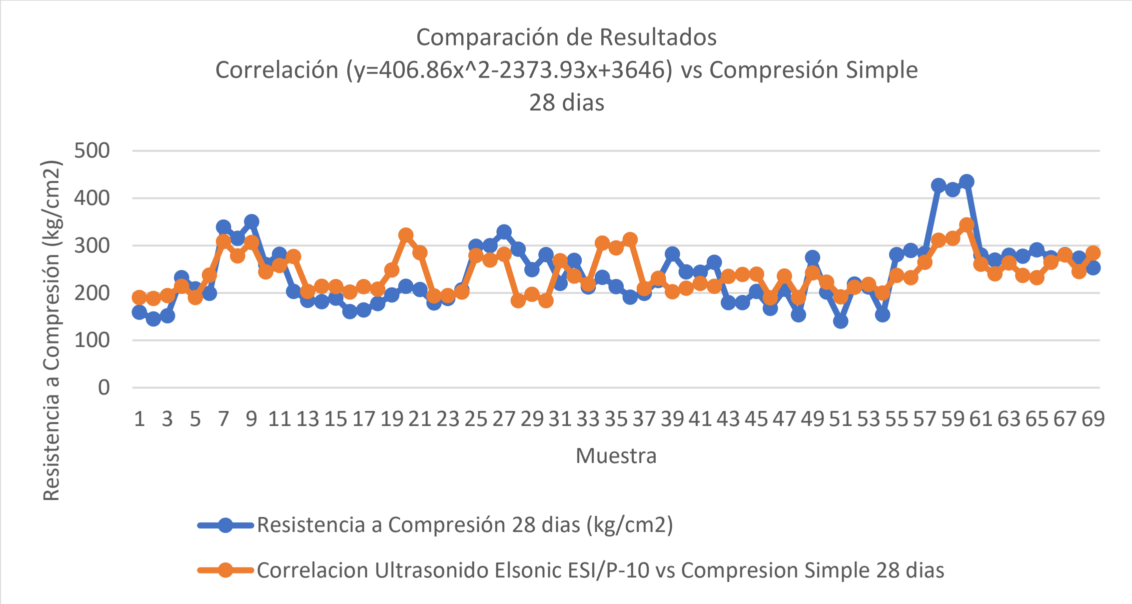


Fuente: Elaboración Propia

En la Figura 52 se muestra que los valores son semejantes con una tendencia marcada, pero también se observa que existe variación en los datos, a pesar de esto sus datos se encuentran muy cercanos a los reales por lo tanto esta ecuación se considera recomendable su uso para determinar la resistencia a compresión simple con los valores dados por el ensayo del esclerómetro para el tipo de hormigones presentados en este trabajo de investigación.

- Para el concreto ensayado a los 28 días, se presenta una ecuación polinomial $y = 406.86x^2 - 2373.93x + 3646$ y un índice de determinación R^2=0.39, donde "x" es el valor de la velocidad de propagación de onda, se presenta su relación entre datos en la Tabla 26 y Figura 53 a continuación:

Figura 53. *Comparación de Resultados entre la Correlación (y=406.86x^2-2373.93x+3646) vs Compresión Simple 28 días*



Fuente: Elaboración Propia

En la Figura 53 se muestra que los valores son semejantes con una tendencia menos marcada, pero también se observa que existe variación menos amplia en los datos que en la figura 51, a pesar de esto sus datos se encuentran cercanos a los reales por lo tanto esta ecuación se considera recomendable su uso para determinar la resistencia a compresión simple con los valores dados por el ensayo de ultrasonido para el tipo de hormigones presentados en este trabajo de investigación.

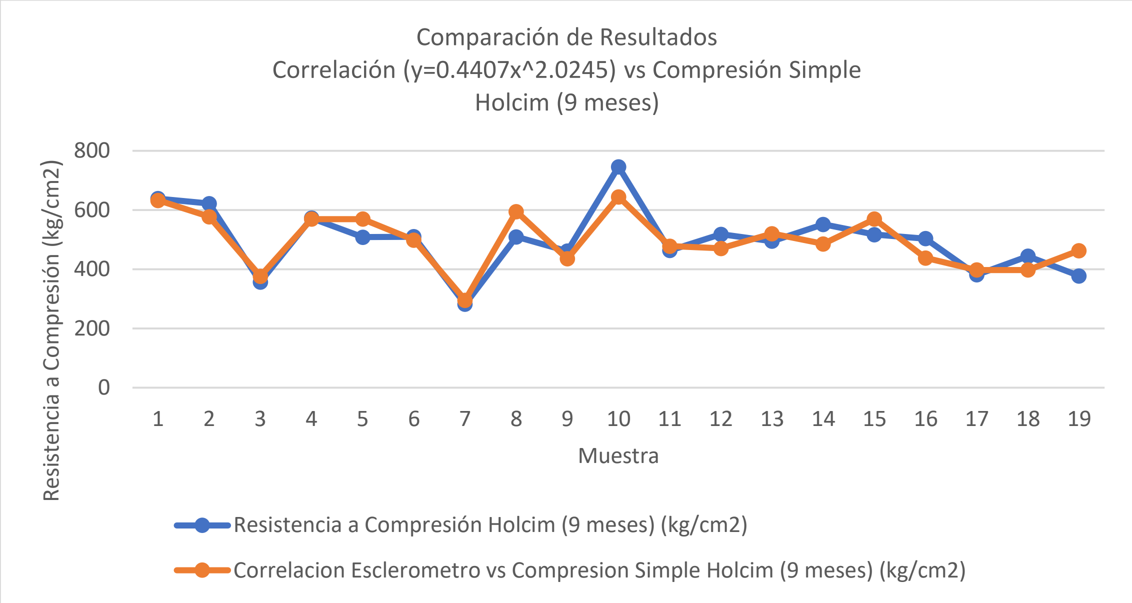
Tabla 27. Comparación de resultados del concreto Holcim (9 meses)

Numero de Muestra	Resistencia (Kg/cm2)	Correlación Esclerómetro vs Compresión Simple Holcim (9 meses) (kg/cm2)	Correlación Ultrasonido Elsonic ESI/P-10 vs Compresión Simple Holcim (9 meses) (kg/cm2)
1	639	633	546
2	622	578	544
3	357	377	342
4	573	569	564
5	509	569	482
6	510	499	486
7	282	295	355
8	509	595	612
9	461	436	580
10	746	644	614
11	463	478	560
12	518	471	495
13	495	520	512
14	552	486	459
15	517	569	547
16	504	438	474
17	382	397	471
18	444	397	442
19	378	463	376

Fuente: Elaboración Propia

- Para el concreto ensayado de Holcim (9 meses), se presenta una ecuación potencial $y = 0.4407x^{2.0245}$ y un índice de determinación R^2=0.795, donde "x" es el valor del índice de rebote, se presenta su relación entre datos en la Tabla 27 y Figura 54 a continuación:

Figura 54. Comparación de Resultados entre la Correlación (y=0.4407x^2.0245) vs Compresión Simple Holcim (9 meses)

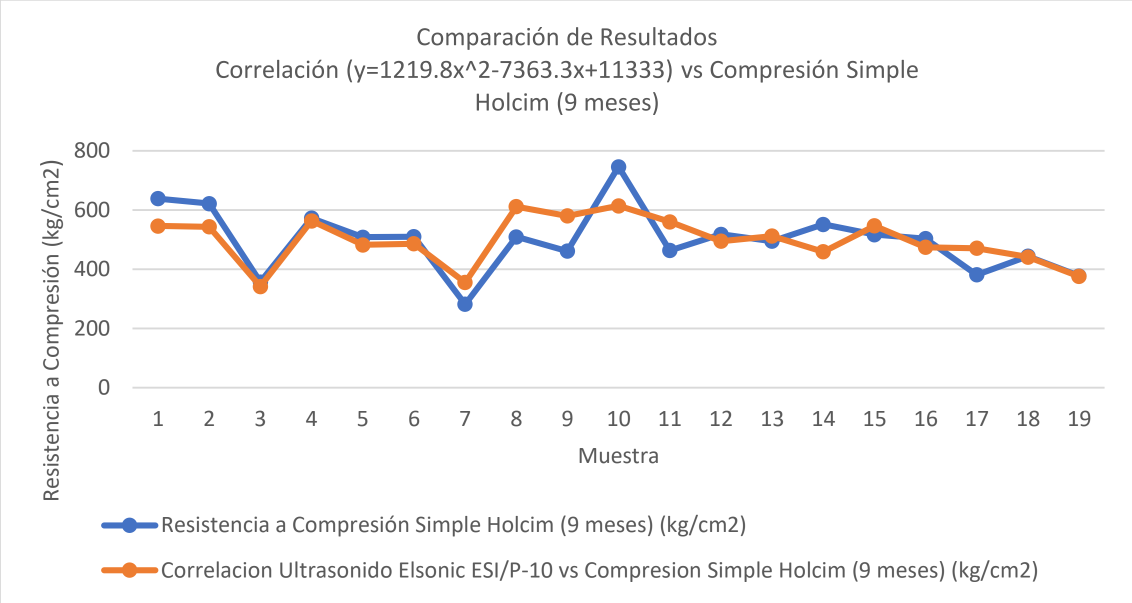


Fuente: Elaboración Propia

En la Figura 54 se muestra que los valores son semejantes con una tendencia marcada, pero también se observa que existe una pequeña variación en los datos, a pesar de esto sus datos se encuentran muy cercanos a los reales por lo tanto esta ecuación se considera recomendable su uso para determinar la resistencia a compresión simple con los valores dados por el ensayo del esclerómetro para el tipo de hormigones de edades mayores a 28 días presentados en este trabajo de investigación.

- Para el concreto ensayado de Holcim (9 meses) se presenta una ecuación polinomial $y = 1219.8x^2 - 7363.3x + 11333$ y un índice de determinación R^2=0.5538, donde "x" es el valor de la velocidad de propagación de onda, se presenta su relación entre datos en la Tabla 27 y Figura 55 a continuación:

Figura 55.Comparación de Resultados entre la Correlación (y=1219x^2-7363.3x+11333) vs Compresión Simple Holcim (9 meses)



Fuente: Elaboración Propia

En la Figura 55 se muestra que los valores son semejantes con una tendencia menos marcada, pero también se observa que existe variación menos amplia, a pesar de esto sus datos se encuentran muy cercanos a los reales por lo tanto esta ecuación se considera recomendable su uso para determinar la resistencia a compresión simple con los valores dados por el ensayo de ultrasonido para el tipo de hormigones presentados en este trabajo de investigación.

6. Discusión de Resultados

En la tesis “Correlación entre las resistencias obtenidas mediante ensayos de compresión y esclerometría en cilindros de concreto normal y modificados con fibra sintética y fibra de acero” de los autores Robinson Builes y Magda Pardo obtuvieron las siguientes ecuaciones para concreto normal:

Tabla 28. Correlaciones Tesis Robinson Builes y Magda Pardo

Edad (días)	Ecuación	R2
7	$y = 9.5008 * e^{0.0346*x}$	0.5471
14	$y = 32.562 * \ln(x) - 73.888$	0.6842
28	$y = 21.822 * e^{0.014*x}$	0.6905

Fuente: Robinson Builes Salazar, 2016

Observamos que estos resultados son parecidos a los obtenidos en esta tesis y mejorados a continuación se presenta las ecuaciones:

Tabla 29. Correlaciones Tesis Issam Saif

Edad (días)	Ecuación	R2
7	$y = 0.1849 * x^{2.0747}$	0.7076
28	$y = 406.86x^2 - 2373.93x + 3646$	0.8000

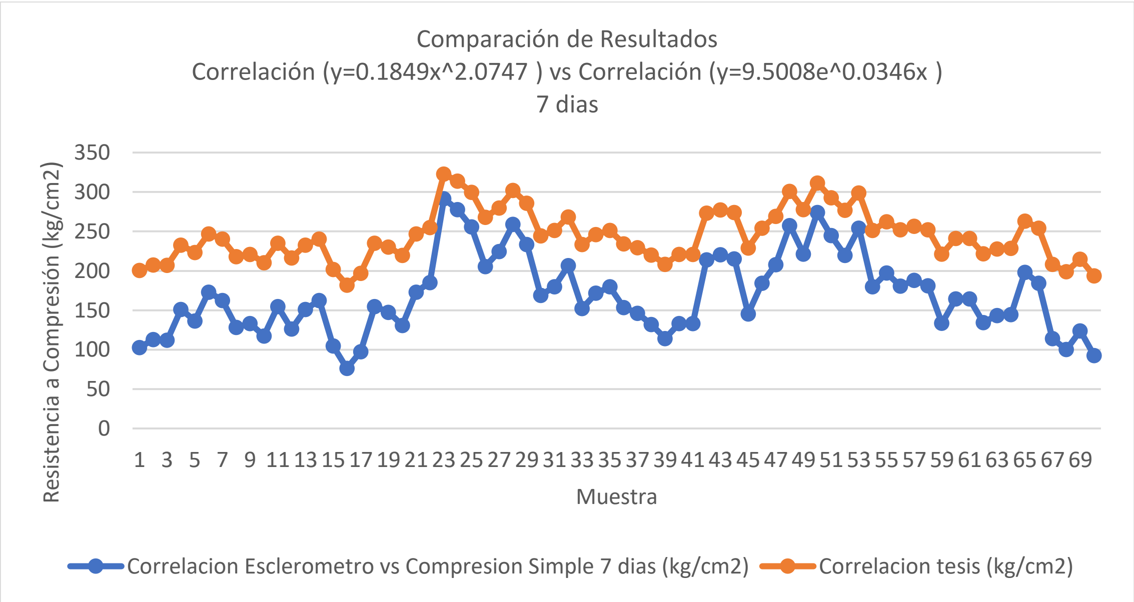
Fuente: Elaboración Propia

La tesis presentada esta concluida y aprobada por la Universidad Católica de Colombia en el año 2016 en Bogotá, comparada con el presente trabajo de investigación nos determina que esta correcta y cumple con los parámetros requeridos.

A continuación, se presenta las Figuras donde se demuestra una comparación de las ecuaciones de la tesis antes mencionada vs los resultados de las correlaciones del trabajo de investigación actual:

- 7 días:

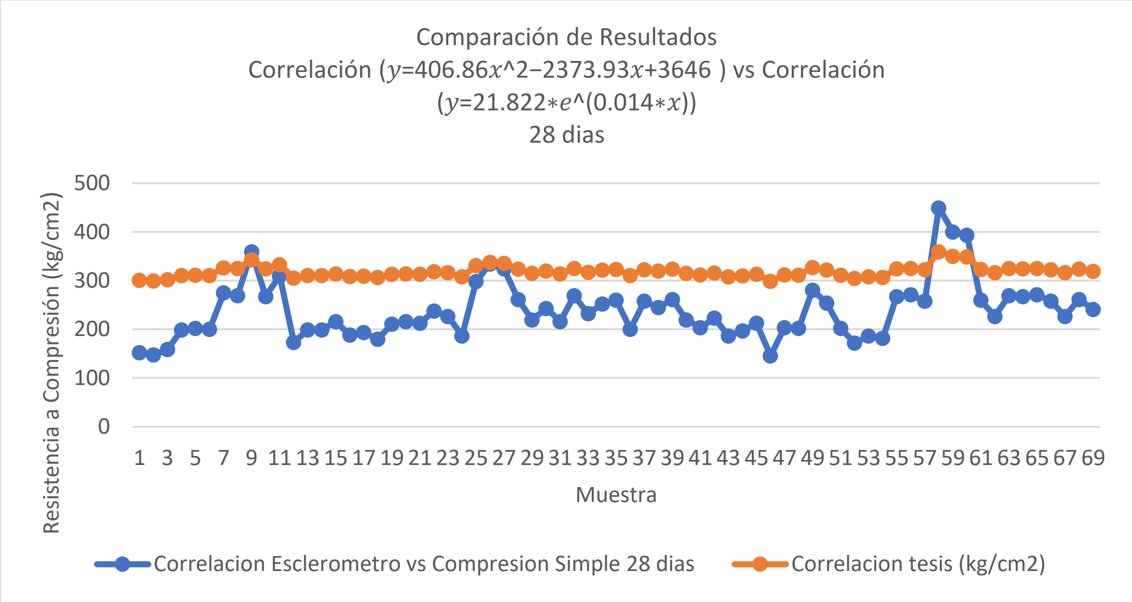
Figura 56. Comparación de Resultados Correlación (y=0.1849x^2.0747) vs Correlación (y=9.5008^0.0346x) 7 días



Fuente: Elaboración Propia

- 28 días:

Figura 57. Comparación de Resultados Correlación (y=406.86x^2-2373.93x+3646) vs Correlación (y=21.822e^0.014x) 28 días



Fuente: Elaboración Propia

En estas dos figuras observamos que las configuraciones graficas son iguales, pero en sus valores se muestra que existe un aumento por parte de las correlaciones presentadas en la tesis con la cual estamos comparando los resultados obtenidos en este trabajo de investigación, esto se debe a que si se disminuye el índice de determinación de la correlación el valor de la resistencia tiende a subir, dándonos que los resultados mostrados están más cerca de la realidad y comprobando que el trabajo de investigación presente está correctamente desarrollado, dándonos valores parecidos a la realidad si sobredimensionarlos.

7. Conclusiones y Recomendaciones

7.1. Conclusiones

1. En la Tabla 20, se observa que la mejor correlación de todas las analizadas es la del esclerómetro con la compresión simple, variando su índice de correlación (R) de 0.84 a 0.90 que nos da una calidad buena de correlación y un rango de relación entre los datos “fuerte – perfecta”. En base a estos resultados se recomienda hacer uso de estas fórmulas, tomando en cuenta que son para este tipo de hormigones en específico.
2. La Tabla 20, muestra claramente que la correlación entre el ultrasonido tico y la compresión simple es bastante baja debido a que sus índices de correlación (R) van de 0.42 a 0.47, dándonos una correlación mala y con un rango de relación entre los datos “débil”. Por este resultado, el uso de estas fórmulas no son recomendadas ya que existe una gran dispersión en sus datos.
3. La Tabla 20, demuestra que las correlaciones entre el ultrasonido Elsonic ESI/P-10 son de una calidad regular ya que se encuentran sus índices de correlación (R) entre 0.56 a 0.74 dándonos un rango de relación de sus datos “Moderada – Fuerte”, mostrando como resultado que estas fórmulas presentadas para su correcto uso siempre se deben comprobar sus resultados con ensayos destructivos.
4. La Tabla 20, nos muestra que la correlación entre el esclerómetro y el ultrasonido Tico es de una calidad mala y tiene un rango de relación entre sus datos entre “Débil” y “Escasa” ya que sus índices de correlación (R) están entre 0.24 a 0.45, dándonos que esta correlación casi no existe entre estos dos aparatos.
5. La Tabla 20, también nos muestra que la correlación entre el ultrasonido Elsonic ESI/P-10 y el esclerómetro tienen rangos de calidad bastante diferentes dándonos en cada caso una calidad “Mala”, “Moderada – Fuerte” y “Fuerte – Perfecta”, en este caso se debe utilizar las ecuaciones correspondientes a los 28 días y los cilindros obtenidos de la hormigonera Holcim dándonos resultados seguros para su uso.

6. Como se observa en las gráficas comparativas mientras mayor sea el índice de determinación de la correlación el valor se acerca al valor real de resistencia a la compresión simple, al contrario, si disminuye dicho índice el valor tiene a sobre dimensionar sus valores.
7. En el caso del ultrasonido Tico se nota que sus resultados son los más dispersos y de peor calidad, con el menor rango de relación llegamos a la conclusión de que este equipo ya cumplió su vida útil, y ha empezado a dar datos erróneos y poco confiables.
8. Los ensayos de resistencia cumplen con la especificación ASTM C39 así que todos los datos utilizados en esta investigación son correctos y han sido utilizados para cada una de las correlaciones.
9. Se observa que las mejores correlaciones existentes entre el esclerómetro y la compresión simple son las de los 28 días y la de Holcim, ya que estos ensayos fueron hechos cuando el hormigón ya consiguió el 100% de su resistencia, a continuación, se presentara en la Tabla 21 sus respectivas formulas y índices de determinación (R^2):

Tabla 30. Fórmulas Esclerómetro vs Compresión Simple 28 días y Holcim

Descripción	Formula	R^2
28 días	$0.3324x^2 + 4.8842x - 104.63$	0.8034
Holcim	$0.4407x^{2.0245}$	0.795

Fuente 1: Elaboración Propia

10. El ensayo del esclerómetro cumple con tener mínimo 7 golpes y máximo de 12 en todos los casos y ninguno excede más de 6 unidades, cumpliendo con la norma ASTM C 805.
11. El ensayo de ultrasonido cumple con todos los parámetros de la norma ASTM C 597 y a su vez nos muestran que el hormigón esta entre una calidad entre buena y regular dándonos así una idea de las condiciones de este.
12. El uso de ensayos no destructivos en obras civiles es muy importante ya que nos ahorra dinero y tiempo, debido a su gran facilidad de uso y no nos deja un daño muy pronunciado como los ensayos destructivos, pero

cabe recalcar que un ensayo no destructivo nunca reemplazara a uno destructivo.

13. Se observa en las Figuras 31, 32, 33 y 34 que el método de dosificación al volumen nos da los mejores resultados, ya que este es el más efectivo para construcciones pequeñas o en toma de muestras cilíndricas de 15x30 cm como en este trabajo de investigación.
14. Se observa en las Figuras 31, 32, 33 y 34 que los métodos de dosificación al peso y al peso con aditivo plastificante dan resultados parecidos, confirmando que el aditivo plastificante solo disminuye la cantidad de agua, pero sin afectar en su resistencia.
15. Los resultados obtenidos en los cilindros desarrollados por los estudiantes podrían representar a los hormigones usados en obra, ya que en la mayoría de las construcciones antiguas no se llevaron un control de calidad riguroso.
16. En esta investigación se trató con cilindros ensayados a los 7 días debido a que se quería conocer que pasaba con los ensayos no destructivos en muestras húmedas, ya que estas representarían a la realidad de una estructura donde la mayoría de las veces no se puede tratar con hormigones totalmente secos, en el caso exhibido en este trabajo de investigación se muestran factores de corrección para superficies húmedas, mostrados en el manual de usuario del esclerómetro y en el caso del ultrasonido se determinó que la velocidad de propagación de onda variaría en un 2%, acercándonos a la realidad y no dependiendo de condiciones de laboratorio para sus resultados.
17. Se observa que los resultados obtenidos en este trabajo de investigación demuestran que el mejor método no destructivo es el esclerómetro ya que sus resultados comparados con la compresión simple nos dan las mejores correlaciones.
18. El ultrasonido no es un buen método para correlacionarse con la resistencia a la compresión, pero es excelente para determinar fallas internas.

7.2. Recomendaciones

1. Se recomienda que para el ensayo de compresión simple se haga las mediciones con la mayor exactitud y que el operador de la maquina tenga la experiencia suficiente.
2. El uso de ensayos no destructivos en obras civiles es muy importante ya que nos ahorra dinero y tiempo, debido a su gran facilidad de uso y no nos deja un daño muy pronunciado como los ensayos destructivos, pero cabe recalcar que un ensayo no destructivo nunca reemplazara a uno destructivo.
3. Se recomienda que la superficie de los cilindros para el ensayo del esclerómetro este completamente limpia y lisa para poder tener resultados sin errores.
4. En el caso de cilindros ensayados a los 7 días o menos se debe tomar en cuenta que el hormigón no ha completado su resistencia al 100 % y el ensayo del esclerómetro se ve afectado, pero al momento de realizar los resultados vemos cambios casi imperceptibles según lo que se observa en las correlaciones realizadas en esta investigación.
5. Los equipos deben estar calibrados para tener un buen desarrollo durante su uso.
6. Es recomendado hacer los ensayos del esclerómetro cuando el hormigón haya completado su tiempo de curado de 28 días.
7. Es importante mencionar que cada una de las estructuras tienen sus propias condiciones, por lo que es recomendable realizar una verificación con ensayos destructivos para poder correlacionar resultados y obtener datos reales del comportamiento del hormigón.
8. El ultrasonido es recomendable usarlo para la detección de fisuras y otros danos en el hormigón ya que este presenta una gran dispersión al ser comparado con la compresión simple en la mayoría de los casos.
9. Cuando se desarrolle el ensayo del ultrasonido se tiene que asegurar que los transductores estén alineados para que no se vean afectados los resultados, al igual que el uso de el gel o vaselina en la superficie del cilindro.

10. Cuando se use el esclerómetro es recomendable aplicar una precarga al cilindro para evitar que se mueva al momento que se realice el golpe y no se vean afectados los datos por este motivo.
11. Esta tesis puede ser utilizada para nuevas investigaciones con el fin de aumentar el número de muestras y poder variar las condiciones de evaluación tales como el ambiente, la humedad o el clima, etc.
12. Se recomienda que exista un riguroso control de calidad al rato de desarrollar los cilindros.
13. Se recomienda trabajar con el método de dosificación al peso para grandes obras ya que este es el utilizado por las hormigoneras para generar su hormigón.

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9. Anexos

INTERNATIONAL

Designation: C39/C39M – 18

Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens[1]

This standard is issued under the fixed designation C39/C39M; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This test method covers determination of compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. It is limited to concrete having a density in excess of 800 kg/m^3 [50 lb/ft^3].

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The inch-pound units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.3 *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.*(**Warning—**Means should be provided to contain concrete fragments during sudden rupture of specimens. Tendency for sudden rupture increases with increasing concrete strength and it is more likely when the testing machine is relatively flexible. The safety precautions given in the Manual are recommended.*)*

1.4 The text of this standard references notes which provide explanatory material. These notes shall not be considered as requirements of the standard.

1.5 *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]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field
C42/C42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C125 Terminology Relating to Concrete and Concrete Aggregates
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C617/C617M Practice for Capping Cylindrical Concrete Specimens
C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
C873/C873M Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds
C943 Practice for Making Test Cylinders and Prisms for Determining Strength and Density of Preplaced-Aggregate Concrete in the Laboratory
C1077 Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation
C1176/C1176M Practice for Making Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Table
C1231/C1231M Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Cylindrical Concrete Specimens
C1435/C1435M Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer
C1604/C1604M Test Method for Obtaining and Testing Drilled Cores of Shotcrete
E4 Practices for Force Verification of Testing Machines
E18 Test Methods for Rockwell Hardness of Metallic Materials

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing for Strength.

Current edition approved Jan. 1, 2018. Published February 2018. Originally approved in 1921. Last previous edition approved in 2017 as C39/C39M – 17b. DOI: 10.1520/C0039_C0039M-18.

[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.

***A Summary of Changes section appears at the end of this standard**

E74 Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines
Manual of Aggregate and Concrete Testing

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, refer to Terminology C125.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bearing block, n*—steel piece to distribute the load from the testing machine to the specimen.

3.2.2 *lower bearing block, n*—steel piece placed under the specimen to distribute the load from the testing machine to the specimen.

3.2.2.1 *Discussion*—The lower bearing block provides a readily machinable surface for maintaining the specified bearing surface. The lower bearing block may also be used to adapt the testing machine to various specimen heights. The lower bearing block is also referred to as *bottom block*, *plain block*, and *false platen*.

3.2.3 *platen, n*—primary bearing surface of the testing machine.

3.2.3.1 *Discussion*—The platen is also referred to as the testing machine *table*.

3.2.4 *spacer, n*—steel piece used to elevate the lower bearing block to accommodate test specimens of various heights.

3.2.4.1 *Discussion*—Spacers are not required to have hardened bearing faces because spacers are not in direct contact with the specimen or the retainers of unbonded caps.

3.2.5 *upper bearing block, n*—steel assembly suspended above the specimen that is capable of tilting to bear uniformly on the top of the specimen.

3.2.5.1 *Discussion*—The upper bearing block is also referred to as the *spherically seated block* and the *suspended block*.

4. Summary of Test Method

4.1 This test method consists of applying a compressive axial load to molded cylinders or cores at a rate which is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

5. Significance and Use

5.1 Care must be exercised in the interpretation of the significance of compressive strength determinations by this test method since strength is not a fundamental or intrinsic property of concrete made from given materials. Values obtained will depend on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding, and fabrication and the age, temperature, and moisture conditions during curing.

5.2 This test method is used to determine compressive strength of cylindrical specimens prepared and cured in accordance with Practices C31/C31M, C192/C192M, C617/C617M, C943, C1176/C1176M, C1231/C1231M, and C1435/C1435M, and Test Methods C42/C42M, C873/C873M, and C1604/C1604M.

5.3 The results of this test method are used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of compliance with specifications; control for evaluating effectiveness of admixtures; and similar uses.

5.4 The individual who tests concrete cylinders for acceptance testing shall meet the concrete laboratory technician requirements of Practice C1077, including an examination requiring performance demonstration that is evaluated by an independent examiner.

NOTE 1—Certification equivalent to the minimum guidelines for ACI Concrete Laboratory Technician, Level I or ACI Concrete Strength Testing Technician will satisfy this requirement.

6. Apparatus

6.1 *Testing Machine*—The testing machine shall be of a type having sufficient capacity and capable of providing the rates of loading prescribed in 8.5.

6.1.1 Verify the accuracy of the testing machine in accordance with Practices E4, except that the verified loading range shall be as required in 6.4. Verification is required:

6.1.1.1 Within 13 months of the last calibration,

6.1.1.2 On original installation or immediately after relocation,

6.1.1.3 Immediately after making repairs or adjustments that affect the operation of the force applying system or the values displayed on the load indicating system, except for zero adjustments that compensate for the mass of bearing blocks or specimen, or both, or

6.1.1.4 Whenever there is reason to suspect the accuracy of the indicated loads.

6.1.2 *Design*—The design of the machine must include the following features:

6.1.2.1 The machine must be power operated and must apply the load continuously rather than intermittently, and without shock. If it has only one loading rate (meeting the requirements of 8.5), it must be provided with a supplemental means for loading at a rate suitable for verification. This supplemental means of loading may be power or hand operated.

6.1.2.2 The space provided for test specimens shall be large enough to accommodate, in a readable position, an elastic calibration device which is of sufficient capacity to cover the potential loading range of the testing machine and which complies with the requirements of Practice E74.

NOTE 2—The types of elastic calibration devices most generally available and most commonly used for this purpose are the circular proving ring or load cell.

6.1.3 *Accuracy*—The accuracy of the testing machine shall be in accordance with the following provisions:

6.1.3.1 The percentage of error for the loads within the proposed range of use of the testing machine shall not exceed ±1.0 % of the indicated load.

6.1.3.2 The accuracy of the testing machine shall be verified by applying five test loads in four approximately equal increments in ascending order. The difference between any two successive test loads shall not exceed one third of the difference between the maximum and minimum test loads.

6.1.3.3 The test load as indicated by the testing machine and the applied load computed from the readings of the verification device shall be recorded at each test point. Calculate the error, E, and the percentage of error, E_p, for each point from these data as follows:

$$E = A - B \quad (1)$$

$$E_p = 100 \; A - B \; / B$$

where:

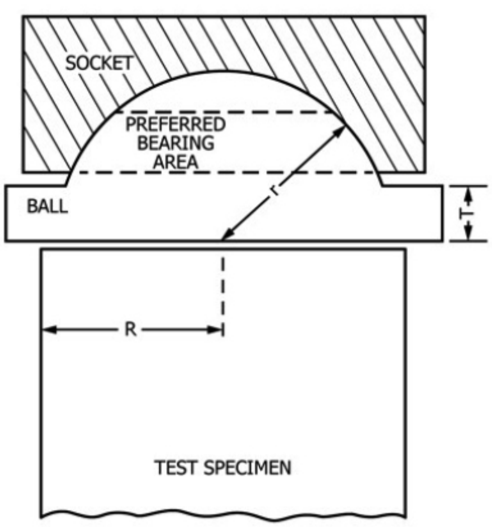
A = load, kN [lbf] indicated by the machine being verified, and

B = applied load, kN [lbf] as determined by the calibrating device.

6.1.3.4 The report on the verification of a testing machine shall state within what loading range it was found to conform to specification requirements rather than reporting a blanket acceptance or rejection. In no case shall the loading range be stated as including loads below the value which is 100 times the smallest change of load estimable on the load-indicating mechanism of the testing machine or loads within that portion of the range below 10 % of the maximum range capacity.

6.1.3.5 In no case shall the loading range be stated as including loads outside the range of loads applied during the verification test.

6.1.3.6 The indicated load of a testing machine shall not be corrected either by calculation or by the use of a calibration diagram to obtain values within the required permissible variation.



$T \geq R - r$

r = radius of spherical portion of upper bearing block

R = nominal radius of specimen

T = thickness of upper bearing block extending beyond the sphere

FIG. 1 Schematic Sketch of Typical Upper Bearing Block

6.2 *Bearing Blocks*—The upper and lower bearing blocks shall conform to the following requirements:

6.2.1 Bearing blocks shall be steel with hardened bearing faces (Note 3).

6.2.2 Bearing faces shall have dimensions at least 3 % greater than the nominal diameter of the specimen.

6.2.3 Except for the inscribed concentric circles described in 6.2.4.7, the bearing faces shall not depart from a plane by more than 0.02 mm [0.001 in.] along any 150 mm [6 in.] length for bearing blocks with a diameter of 150 mm [6 in.] or larger, or by more than 0.02 mm [0.001 in.] in any direction of smaller bearing blocks. New bearing blocks shall be manufactured within one-half of this tolerance.

NOTE 3—It is desirable that the bearing faces of bearing blocks have a Rockwell hardness at least 55 HRC as determined by Test Methods E18.

NOTE 4—Square bearing faces are permissible for the bearing blocks.

6.2.4 *Upper Bearing Block*—The upper bearing block shall conform to the following requirements:

6.2.4.1 The upper bearing block shall be spherically seated and the center of the sphere shall coincide with the center of the bearing face within ±5 % of the radius of the sphere.

6.2.4.2 The ball and the socket shall be designed so that the steel in the contact area does not permanently deform when loaded to the capacity of the testing machine.

NOTE 5—The preferred contact area is in the form of a ring (described as *preferred bearing area*) as shown in Fig. 1.

6.2.4.3 Provision shall be made for holding the upper bearing block in the socket. The design shall be such that the bearing face can be rotated and tilted at least 4° in any direction.

6.2.4.4 If the upper bearing block is a two-piece design composed of a spherical portion and a bearing plate, a mechanical means shall be provided to ensure that the spherical portion is fixed and centered on the bearing plate.

6.2.4.5 The diameter of the sphere shall be at least 75 % of the nominal diameter of the specimen. If the diameter of the sphere is smaller than the diameter of the specimen, the portion of the bearing face extending beyond the sphere shall have a thickness not less than the difference between the radius of the sphere and radius of the specimen (see Fig. 1). The least dimension of the bearing face shall be at least as great as the diameter of the sphere.

6.2.4.6 The dimensions of the bearing face of the upper bearing block shall not exceed the following values:

Nominal Diameter of Specimen, mm [in.]	Maximum Diameter of Round Bearing Face, mm [in.]	Maximum Dimensions of Square Bearing Face, mm [in.]
50 [2]	105 [4]	105 by 105 [4 by 4]
75 [3]	130 [5]	130 by 130 [5 by 5]
100 [4]	165 [6.5]	165 by 165 [6.5 by 6.5]
150 [6]	255 [10]	255 by 255 [10 by 10]
200 [8]	280 [11]	280 by 280 [11 by 11]

6.2.4.7 If the diameter of the bearing face of the upper bearing block exceeds the nominal diameter of the specimen by more than 13 mm [0.5 in.], concentric circles not more than 0.8 mm [0.03 in.] deep and not more than 1 mm [0.04 in.] wide shall be inscribed on the face of upper bearing block to facilitate proper centering.

6.2.4.8 At least every six months, or as specified by the manufacturer of the testing machine, clean and lubricate the curved surfaces of the socket and of the spherical portion of the upper bearing block. The lubricant shall be a petroleum-type oil such as conventional motor oil or as specified by the manufacturer of the testing machine.

NOTE 6—To ensure uniform seating, the upper bearing block is designed to tilt freely as it comes into contact with the top of the specimen. After contact, further rotation is undesirable. Friction between the socket and the spherical portion of the head provides restraint against further rotation during loading. Pressure-type greases can reduce the desired friction and permit undesired rotation of the spherical head and should not be used unless recommended by the manufacturer of the testing machine. Petroleum-type oil such as conventional motor oil has been shown to permit the necessary friction to develop.

6.2.5 *Lower Bearing Block*—The lower bearing block shall conform to the following requirements:

6.2.5.1 The lower bearing block shall be solid.

6.2.5.2 The top and bottom surfaces of the lower bearing block shall be parallel to each other.

6.2.5.3 The lower bearing block shall be at least 25 mm [1.0 in.] thick when new, and at least 22.5 mm [0.9 in.] thick after resurfacing.

6.2.5.4 The lower bearing block shall be fully supported by the platen of the testing machine or by any spacers used.

6.2.5.5 If the testing machine is designed that the platen itself is readily maintained in the specified surface condition, a lower bearing block is not required.

NOTE 7—The lower bearing block may be fastened to the platen of the testing machine.

NOTE 8—Inscribed concentric circles as described in 6.2.4.7 are optional on the lower bearing block.

6.3 *Spacers*—If spacers are used, the spacers shall be placed under the lower bearing block and shall conform to the following requirements:

6.3.1 Spacers shall be solid steel. One vertical opening located in the center of the spacer is permissible. The maximum diameter of the vertical opening is 19 mm [0.75 in.].

6.3.2 The top and bottom surfaces of the spacer shall be parallel to each other.

6.3.3 Spacers shall be fully supported by the platen of the test machine.

6.3.4 Spacers shall fully support the lower bearing block and any spacers above.

6.3.5 Spacers shall not be in direct contact with the specimen or the retainers of unbonded caps.

6.4 *Load Indication*—The testing machine shall be equipped with either a dial or digital load indicator.

6.4.1 The verified loading range shall not include loads less than 100 times the smallest change of load that can be read.

6.4.2 A means shall be provided that will record, or indicate until reset, the maximum load to an accuracy within 1.0 % of the load.

6.4.3 If the load is displayed on a dial, the graduated scale shall be readable to at least the nearest 0.1 % of the full scale load (Note 9). The dial shall be readable within 1.0 % of the indicated load at any given load level within the loading range. The dial pointer shall be of sufficient length to reach the graduation marks. The width of the end of the pointer shall not exceed the clear distance between the smallest graduations. The scale shall be provided with a labeled graduation line load corresponding to zero load. Each dial shall be equipped with a zero adjustment located outside the dial case and accessible from the front of the machine while observing the zero mark and dial pointer.

NOTE 9—Readability is considered to be 0.5 mm [0.02 in.] along the arc described by the end of the pointer. If the spacing is between 1 and 2 mm [0.04 and 0.08 in.], one half of a scale interval is considered readable. If the spacing is between 2 and 3 mm [0.08 and 0.12 in.], one third of a scale interval is considered readable. If the spacing is 3 mm [0.12 in.] or more, one fourth of a scale interval is considered readable.

6.4.4 If the load is displayed in digital form, the numbers must be large enough to be read. The numerical increment shall not exceed 0.1 % of the full scale load of a given loading range. Provision shall be made for adjusting the display to indicate a value of zero when no load is applied to the specimen.

6.5 Documentation of the calibration and maintenance of the testing machine shall be in accordance with Practice C1077.

7. Specimens

7.1 Specimens shall not be tested if any individual diameter of a cylinder differs from any other diameter of the same cylinder by more than 2 %.

NOTE 10—This may occur when single use molds are damaged or deformed during shipment, when flexible single use molds are deformed during molding, or when a core drill deflects or shifts during drilling.

7.2 Prior to testing, neither end of test specimens shall depart from perpendicularity to the axis by more than 0.5° (approximately equivalent to 1 mm in 100 mm [0.12 in. in 12 in.]). The ends of compression test specimens that are not plane within 0.050 mm [0.002 in.] shall be sawed or ground to meet that tolerance, or capped in accordance with either Practice C617/C617M or, when permitted, Practice C1231/C1231M. The diameter used for calculating the cross-sectional area of the test specimen shall be determined to the nearest 0.25 mm [0.01 in.] by averaging two diameters measured at right angles to each other at about midheight of the specimen.

7.3 The number of individual cylinders measured for determination of average diameter is not prohibited from being reduced to one for each ten specimens or three specimens per day, whichever is greater, if all cylinders are known to have been made from a single lot of reusable or single-use molds which consistently produce specimens with average diameters within a range of 0.5 mm [0.02 in.]. When the average diameters do not fall within the range of 0.5 mm [0.02 in.] or when the cylinders are not made from a single lot of molds, each cylinder tested must be measured and the value used in calculation of the unit compressive strength of that specimen. When the diameters are measured at the reduced frequency, the cross-sectional areas of all cylinders tested on that day shall be computed from the average of the diameters of the three or more cylinders representing the group tested that day.

7.4 If the purchaser of the testing services or the specifier of the tests requests measurement of the specimen density, determine the specimen density before capping by either 7.4.1

(specimen dimension method) or 7.4.2 (submerged weighing method). For either method, use a balance or scale that is accurate to within 0.3 % of the mass being measured.

7.4.1 Remove any surface moisture with a towel and measure the mass of the specimen. Measure the length of the specimen to the nearest 1 mm [0.05 in.] at three locations spaced evenly around the circumference. Compute the average length and record to the nearest 1 mm [0.05 in.].

7.4.2 Remove any surface moisture with a towel and determine the mass of the specimen in air. Submerge the specimen in water at a temperature of 23.0 ± 2.0°C [73.5 ± 3.5°F] for 15 ± 5 sec. Then, determine the apparent mass of the specimen while submerged under water.

7.5 When density determination is not required and the length to diameter ratio is less than 1.8 or more than 2.2, measure the length of the specimen to the nearest 0.05 D.

8. Procedure

8.1 Compression tests of moist-cured specimens shall be made as soon as practicable after removal from moist storage.

8.2 Test specimens shall be kept moist by any convenient method during the period between removal from moist storage and testing. They shall be tested in the moist condition.

8.3 Tolerances for specimen ages are as follows:

Test Age[A]	Permissible Tolerance
24 h	±0.5 h
3 days	±2 h
7 days	±6 h
28 days	±20 h
90 days	±2 days

[A]For test ages not listed, the test age tolerance is ±2.0% of the specified age.

8.3.1 Unless otherwise specified by the specifier of tests, for this test method the test age shall start at the beginning of casting specimens.

8.4 *Placing the Specimen*—Place the lower bearing block, with the hardened face up, on the table or platen of the testing machine. Wipe clean the bearing faces of the upper and lower bearing blocks, spacers if used, and of the specimen. If using unbonded caps, wipe clean the bearing surfaces of the retainers and center the unbonded caps on the specimen. Place the specimen on the lower bearing block and align the axis of the specimen with the center of thrust of the upper bearing block.

NOTE 11—Although the lower bearing block may have inscribed concentric circles to assist with centering the specimen, final alignment is made with reference to the upper bearing block.

8.4.1 *Zero Verification and Block Seating*—Prior to testing the specimen, verify that the load indicator is set to zero. In cases where the indicator is not properly set to zero, adjust the indicator (Note 12). After placing the specimen in the machine but prior to applying the load on the specimen, tilt the movable portion of the spherically seated block gently by hand so that the bearing face appears to be parallel to the top of the test specimen.

NOTE 12—The technique used to verify and adjust load indicator to zero will vary depending on the machine manufacturer. Consult your owner's manual or compression machine calibrator for the proper technique.

8.4.2 *Verification of Alignment When Using Unbonded Caps*—If using unbonded caps, verify the alignment of the specimen after application of load, but before reaching 10 % of the anticipated specimen strength. Check to see that the axis of the cylinder does not depart from vertical by more than 0.5° (Note 13) and that the ends of the cylinder are centered within the retaining rings. If the cylinder alignment does not meet these requirements, release the load, and carefully recenter the specimen. Reapply load and recheck specimen centering and alignment. A pause in load application to check cylinder alignment is permissible.

NOTE 13—An angle of 0.5° is equal to a slope of approximately 1 mm in 100 mm [⅛ inches in 12 inches]

8.5 *Rate of Loading*—Apply the load continuously and without shock.

8.5.1 The load shall be applied at a rate of movement (platen to crosshead measurement) corresponding to a stress rate on the specimen of 0.25 ± 0.05 MPa/s [35 ± 7 psi/s] (see Note 14). The designated rate of movement shall be maintained at least during the latter half of the anticipated loading phase.

NOTE 14—For a screw-driven or displacement-controlled testing machine, preliminary testing will be necessary to establish the required rate of movement to achieve the specified stress rate. The required rate of movement will depend on the size of the test specimen, the elastic modulus of the concrete, and the stiffness of the testing machine.

8.5.2 During application of the first half of the anticipated loading phase, a higher rate of loading shall be permitted. The higher loading rate shall be applied in a controlled manner so that the specimen is not subjected to shock loading.

8.5.3 Make no adjustment in the rate of movement (platen to crosshead) as the ultimate load is being approached and the stress rate decreases due to cracking in the specimen.

8.6 Apply the compressive load until the load indicator shows that the load is decreasing steadily and the specimen displays a well-defined fracture pattern (Types 1 to 4 in Fig. 2). For a testing machine equipped with a specimen break detector, automatic shut-off of the testing machine is prohibited until the load has dropped to a value that is less than 95 % of the peak load. When testing with unbonded caps, a corner fracture similar to a Type 5 or 6 pattern shown in Fig. 2 may occur before the ultimate capacity of the specimen has been attained. Continue compressing the specimen until the user is certain that the ultimate capacity has been attained. Record the maximum load carried by the specimen during the test, and note the type of fracture pattern according to Fig. 2. If the fracture pattern is not one of the typical patterns shown in Fig. 2, sketch and describe briefly the fracture pattern. If the measured strength is lower than expected, examine the fractured concrete and note the presence of large air voids, evidence of segregation, whether fractures pass predominantly around or through the coarse aggregate particles, and verify end preparations were in accordance with Practice C617/C617M or Practice C1231/C1231M.

9. Calculation

9.1 Calculate the compressive strength of the specimen as follows:

SI units:

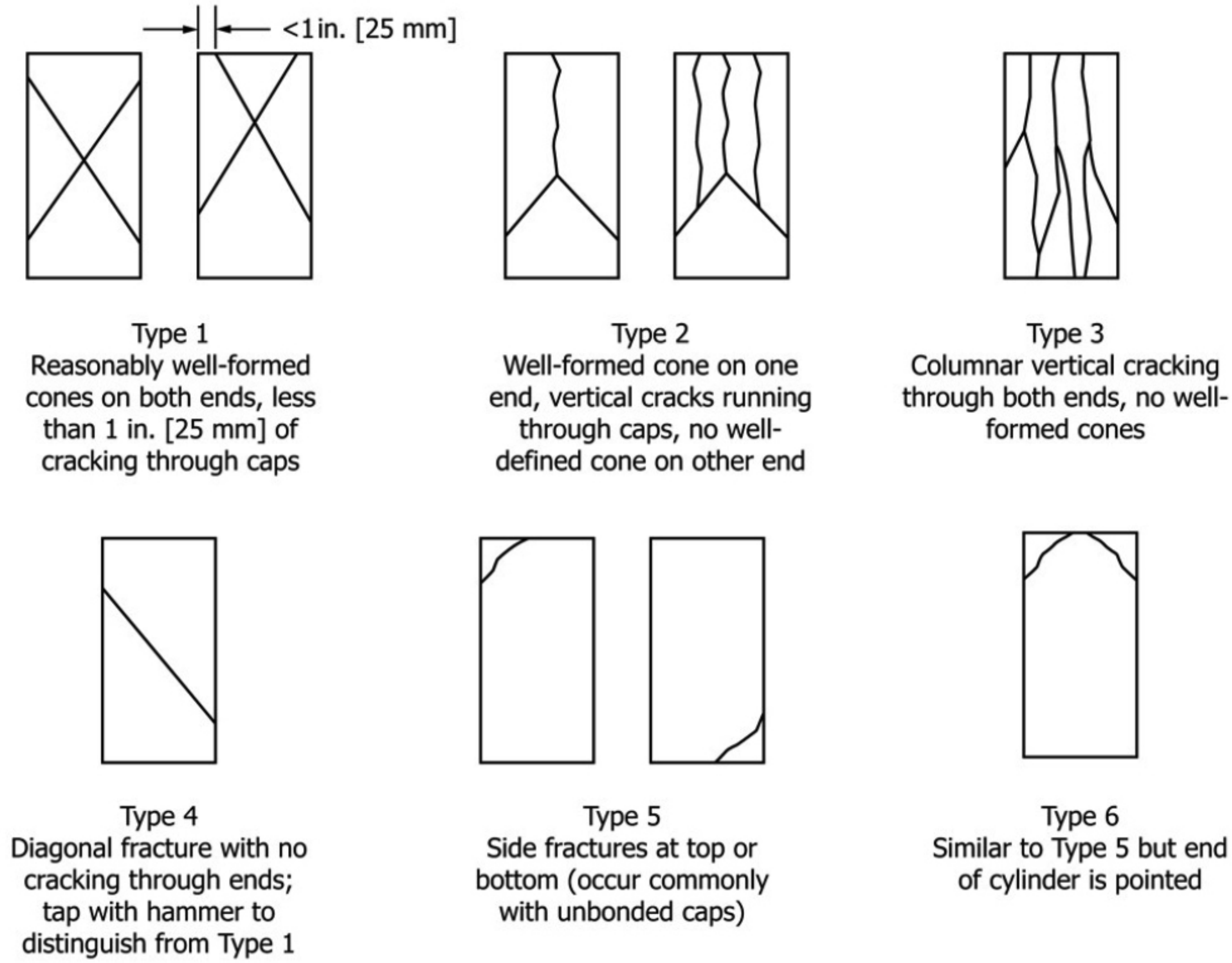


FIG. 2 Schematic of Typical Fracture Patterns

$$f_{cm} = \frac{4000 P_{max}}{\pi D^2} \quad (2)$$

Inch-pound units:

$$f_{cm} = \frac{4 P_{max}}{\pi D^2} \quad (3)$$

where:

f_{cm} = compressive strength, MPa [psi],
P_{max} = maximum load, kN [lbf], and
D = average measured diameter, mm [in.].

9.2 If the specimen length to diameter ratio is 1.75 or less, correct the result obtained in 9.1 by multiplying by the appropriate correction factor shown in the following table:

L/D:	1.75	1.50	1.25	1.00
Factor:	0.98	0.96	0.93	0.87

Use interpolation to determine correction factors for L/D values between those given in the table.

NOTE 15—Correction factors depend on various conditions such as moisture condition, strength level, and elastic modulus. Average values are given in the table. These correction factors apply to low-density concrete weighing between 1600 and 1920 kg/m³ [100 and 120 lb/ft³] and to normal-density concrete. They are applicable to concrete dry or soaked at the time of loading and for nominal concrete strengths from 14 to 42 MPa [2000 to 6000 psi]. For strengths higher than 42 MPa [6000 psi] correction factors may be larger than the values listed above[3].

9.3 If required, calculate the specimen density to the nearest 10 kg/m³ [1 lb/ft³] using the applicable method.

9.3.1 If specimen density is determined based on specimen dimensions, calculate specimen density as follows:

SI units:

$$\rho_s = \frac{4 \times 10^9 \times W}{L \times D^2 \times \pi} \quad (4)$$

Inch-pound units:

$$\rho_s = \frac{6912 \times W}{L \times D^2 \times \pi}$$ [redacted]

where:

ρ_s = specimen density, kg/m³ [lb/ft³],
W = mass of specimen in air, kg [lb],
L = average measured length, mm [in.], and
D = average measured diameter, mm [in.].

9.3.2 If the specimen density is based on submerged weighing, calculate the specimen density as follows:

[3] Bartlett, F.M. and MacGregor, J.G., "Effect of Core Length-to-Diameter Ratio on Concrete Core Strength," *ACI Materials Journal*, Vol 91, No. 4, July-August, 1994, pp. 339–348.

$$\rho_s = \frac{W \times \gamma_w}{W - W_s} \tag{6}$$

where:

ρ_s = specimen density, kg/m^3 [lb/ft^3],
W = mass of specimen in air, kg [lb],
W_s = apparent mass of submerged specimen, kg [lb], and
γ_w = density of water at 23°C [73.5°F] = 997.5 kg/m^3 [62.27 lb/ft^3].

10. Report

10.1 Report the following information:

10.1.1 Identification number,

10.1.2 Average measured diameter (and measured length, if outside the range of 1.8 *D* to 2.2 *D*), in millimetres [inches],

10.1.3 Cross-sectional area, in square millimetres [square inches],

10.1.4 Maximum load, in kilonewtons [pounds-force],

10.1.5 Compressive strength rounded to the nearest 0.1 MPa [10 psi],

10.1.6 If the average of two or more companion cylinders tested at the same age is reported, calculate the average compressive strength using the unrounded individual compressive strength values. Report the average compressive-strength rounded to the nearest 0.1 MPa [10 psi].

10.1.7 Type of fracture (see Fig. 2),

10.1.8 Defects in either specimen or caps,

10.1.9 Age of specimen at time of testing. Report age in days for ages three days or greater, report age in hours if the age is less than three days,

NOTE 16—If software limitations prevent reporting the specimen age in hours, the age of the specimen in hours may be included in a note in the report.

10.1.10 If determined, the density to the nearest 10 kg/m^3 [1 lb/ft^3].

11. Precision and Bias

11.1 *Precision*

11.1.1 *Single-Operator Precision*—The following table provides the single-operator precision of tests of 150 by 300 mm [6 by 12 in.] and 100 by 200 mm [4 by 8 in.] cylinders made from a well-mixed sample of concrete under laboratory conditions and under field conditions (see 11.1.2).

	Coefficient of Variation[4]	Acceptable Range[4] of Individual Cylinder Strengths	
		2 cylinders	3 cylinders
150 by 300 mm [6 by 12 in.]			
Laboratory conditions	2.4 %	6.6 %	7.8 %
Field conditions	2.9 %	8.0 %	9.5 %
100 by 200 mm [4 by 8 in.]			
Laboratory conditions	3.2 %	9.0 %	10.6 %

[4] These numbers represent respectively the (1s %) and (d2s %) limits as described in Practice C670.

11.1.2 The single-operator coefficient of variation represents the expected variation of measured strength of companion cylinders prepared from the same sample of concrete and tested by one laboratory at the same age. The values given for the single-operator coefficient of variation of 150 by 300 mm [6 by 12 in.] cylinders are applicable for compressive strengths between 15 to 55 MPa [2000 to 8000 psi] and those for 100 by 200 mm [4 by 8 in.] cylinders are applicable for compressive strengths between 17 to 32 MPa [2500 and 4700 psi]. The single-operator coefficients of variation for 150 by 300 mm [6 by 12 in.] cylinders are derived from CCRL concrete proficiency sample data for laboratory conditions and a collection of 1265 test reports from 225 commercial testing laboratories in 1978.[5] The single-operator coefficient of variation of 100 by 200 mm [4 by 8 in.] cylinders are derived from CCRL concrete proficiency sample data for laboratory conditions.

11.1.3 *Multilaboratory Precision*—The multi-laboratory coefficient of variation for compressive strength test results of 150 by 300 mm [6 by 12 in.] cylinders has been found to be 5.0 %[4]; therefore, the results of properly conducted tests by two laboratories on specimens prepared from the same sample of concrete are not expected to differ by more than 14 %[4] of the average (see Note 17). A strength test result is the average of two cylinders tested at the same age.

NOTE 17—The multilaboratory precision does not include variations associated with different operators preparing test specimens from split or independent samples of concrete. These variations are expected to increase the multilaboratory coefficient of variation.

11.1.4 The multilaboratory data were obtained from six separate organized strength testing round robin programs where 150 by 300 mm [6 by 12 in.] cylindrical specimens were prepared at a single location and tested by different laboratories. The range of average strength from these programs was 17.0 to 90 MPa [2500 to 13 000 psi].

NOTE 18—Subcommittee C09.61 will continue to examine recent concrete proficiency sample data and field test data and make revisions to precisions statements when data indicate that they can be extended to cover a wider range of strengths and specimen sizes.

11.2 *Bias*—Since there is no accepted reference material, no statement on bias is being made.

12. Keywords

12.1 concrete core; concrete cylinder; concrete specimen; concrete strength; compressive strength; core; cylinder; drilled core; strength

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:C09-1006. Contact ASTM Customer Service at service@astm.org.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue (C39/C39M–17b) that may impact the use of this standard. (Approved Jan. 1, 2018)

(1) Added Practice C943 to Referenced Documents and Practice C943 as a source of specimens.

(2) Revised 8.3.

Designation: C597 − 16

Standard Test Method for Pulse Velocity Through Concrete[1]

This standard is issued under the fixed designation C597; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This test method covers the determination of the propagation velocity of longitudinal stress wave pulses through concrete. This test method does not apply to the propagation of other types of stress waves through concrete.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C125 Terminology Relating to Concrete and Concrete Aggregates

C215 Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens

C823 Practice for Examination and Sampling of Hardened Concrete in Constructions

E1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions*—Refer to Terminology C125 and the section related to ultrasonic examination in Terminology E1316 for definitions of terms used in this test method.

4. Summary of Test Method

4.1 Pulses of longitudinal stress waves are generated by an electro-acoustical transducer that is held in contact with one surface of the concrete under test. After traversing through the concrete, the pulses are received and converted into electrical energy by a second transducer located a distance L from the transmitting transducer. The transit time T is measured electronically. The pulse velocity V is calculated by dividing L by T.

5. Significance and Use

5.1 The pulse velocity, V, of longitudinal stress waves in a concrete mass is related to its elastic properties and density according to the following relationship:

$$V = \sqrt{\frac{E\,(1-\mu)}{\rho\,(1+\mu)(1-2\,\mu)}} \quad (1)$$

where:

E = dynamic modulus of elasticity,
μ = dynamic Poisson's ratio, and
ρ = density.

5.2 This test method is applicable to assess the uniformity and relative quality of concrete, to indicate the presence of voids and cracks, and to evaluate the effectiveness of crack repairs. It is also applicable to indicate changes in the properties of concrete, and in the survey of structures, to estimate the severity of deterioration or cracking. If used to monitor changes in condition over time, test locations are to be marked on the structure to ensure that tests are repeated at the same positions.

5.3 The degree of saturation of the concrete affects the pulse velocity, and this factor must be considered when evaluating test results (Note 1). In addition, the pulse velocity in saturated concrete is less sensitive to changes in its relative quality.

NOTE 1—The pulse velocity in saturated concrete may be up to 5 % higher than in dry concrete.[3]

5.4 The pulse velocity is independent of the dimensions of the test object provided reflected waves from boundaries do not complicate the determination of the arrival time of the directly transmitted pulse. The least dimension of the test object must exceed the wavelength of the ultrasonic vibrations (Note 2).

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.64 on Nondestructive and In-Place Testing.

Current edition approved April 1, 2016. Published May 2016. Originally approved in 1967. Last previous edition approved in 2009 as C597 – 09. DOI: 10.1520/C0597-16.

[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] Bungey, J. H., Millard, S. G., and Grantham, M.G., 2006 *Testing of Concrete in Structures*, 4th ed., Taylor & Francis, 339 pp.

***A Summary of Changes section appears at the end of this standard**

NOTE 2—The wavelength of the vibrations equals the pulse velocity divided by the frequency of vibrations. For example, for a frequency of 54 kHz and a pulse velocity of 3500 m/s, the wavelength is 3500/54000 = 0.065 m.

5.5 The accuracy of the measurement depends upon the ability of the operator to determine precisely the distance between the transducers and of the equipment to measure precisely the pulse transit time. The received signal strength and measured transit time are affected by the coupling of the transducers to the concrete surfaces. Sufficient coupling agent and pressure must be applied to the transducers to ensure stable transit times. The strength of the received signal is also affected by the travel path length and by the presence and degree of cracking or deterioration in the concrete tested.

NOTE 3—Proper coupling can be verified by viewing the shape and magnitude of the received waveform. The waveform should have a decaying sinusoidal shape. The shape can be viewed by means of outputs to an oscilloscope or digitized display inherent in the device.

5.6 The measured quantity in this test method is transit time, from which an 'apparent' pulse velocity is calculated based on the distance between the transducers. Not all forms of deterioration or damage actually change the pulse velocity of the material, but they affect the actual path for the pulse to travel from transmitter to receiver. For example, load-induced cracking will increase the true path length of the pulse and thus increase the measured pulse transit time. The true path length cannot be measured. Because the distance from transmitting to receiving transducer is used in the calculation, the presence of the cracking results in a decrease in the 'apparent' pulse velocity even though the actual pulse velocity of the material has not changed. Many forms of cracking and deterioration are directional in nature. Their influence on transit time measurements will be affected by their orientation relative to the pulse travel path.

5.7 The results obtained by the use of this test method are not to be considered as a means of measuring strength nor as an adequate test for establishing compliance of the modulus of elasticity of field concrete with that assumed in the design. The longitudinal resonance method in Test Method C215 is recommended for determining the dynamic modulus of elasticity of test specimens obtained from field concrete because Poisson's ratio does not have to be known.

NOTE 4—If circumstances warrant, a velocity-strength (or velocity-modulus) relationship may be established by the determination of pulse velocity and compressive strength (or modulus of elasticity) on a number of specimens of a concrete. This relationship may serve as a basis for the estimation of strength (or modulus of elasticity) by further pulse-velocity tests on that concrete. Refer to ACI 228.1R[4] for guidance on the procedures for developing and using such a relationship.

5.8 The procedure is applicable in both field and laboratory testing regardless of size or shape of the specimen within the limitations of available pulse-generating sources.

NOTE 5—Presently available test equipment limits path lengths to approximately 50-mm minimum and 15-m maximum, depending, in part, upon the frequency and intensity of the generated signal. The upper limit of the path length depends partly on surface conditions and partly on the characteristics of the interior concrete under investigation. A preamplifier at the receiving transducer may be used to increase the maximum path length that can be tested. The maximum path length is obtained by using transducers of relatively low resonant frequencies (20 to 30 kHz) to minimize the attenuation of the signal in the concrete. (The resonant frequency of the transducer assembly determines the frequency of vibration in the concrete.) For the shorter path lengths where loss of signal is not the governing factor, it is preferable to use resonant frequencies of 50 kHz or higher to achieve more accurate transit-time measurements and hence greater sensitivity.

5.9 Because the pulse velocity in steel is up to double that in concrete, the pulse-velocity measured in the vicinity of the reinforcing steel will be higher than in plain concrete of the same composition. If possible, avoid measurements close to steel parallel to the direction of pulse propagation.

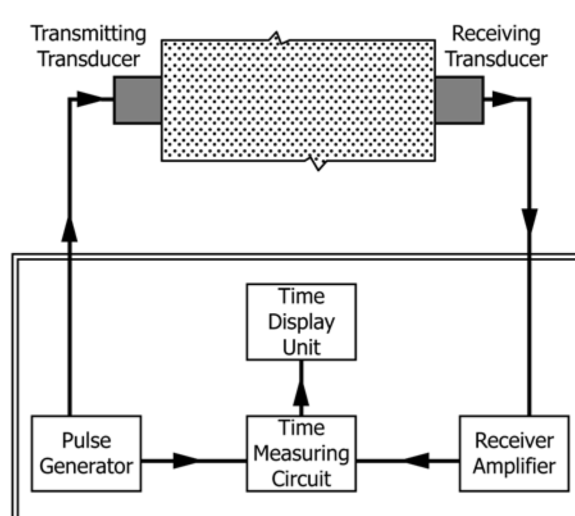
6. Apparatus

6.1 The testing apparatus, shown schematically in Fig. 1, consists of a pulse generator, a pair of transducers (transmitter and receiver), an amplifier, a time measuring circuit, a time display unit, and connecting cables.

6.1.1 *Pulse Generator and Transmitting Transducer*—The pulse generator shall consist of circuitry for generating pulses of voltage (Note 6). The transducer for transforming these electronic pulses into wave bursts of mechanical energy shall have a resonant frequency in the range from 20 to 100 kHz (Note 7). The pulse generator shall produce repetitive pulses at a rate of at least 3 pulses per second. The time interval between pulses shall exceed the decay time for the transmitting transducer. The transducer shall be constructed of piezoelectric, magnetostrictive, or other voltage-sensitive material, and housed for protection. A triggering pulse shall be produced to start the time measuring circuit.

NOTE 6—The pulse voltage affects the transducer power output and the maximum penetration of the longitudinal stress waves. Voltage pulses of 500 to 1000 V have been used successfully.

NOTE 7—Transducers with higher resonant frequencies have been used successfully in relatively small laboratory specimens.



NOTE 1—It is advantageous to incorporate the pulse generator, time measuring circuit, receiver amplifier, and time display into one unit.

FIG. 1 Schematic of Pulse Velocity Apparatus

[4] "In-Place Methods to Estimate Concrete Strength," ACI 228.1R, American Concrete Institute, Farmington Hills, MI.

6.1.2 *Receiving Transducer and Amplifier*—The receiving transducer shall be similar to the transmitting transducer. The voltage generated by the receiver shall be amplified as necessary to produce triggering pulses to the time-measuring circuit. The amplifier shall have a flat response between one half and three times the resonant frequency of the receiving transducer.

6.1.3 *Time-Measuring Circuit*—The time-measuring circuit and the associated triggering pulses shall be capable of providing an overall time-measurement resolution of at least 1 µs. Time measurement is initiated by a triggering voltage from the pulse generator, and the time measuring circuit shall operate at the repetition frequency of the pulse generator. The time-measuring circuit shall provide an output when the received pulse is detected, and this output shall be used to determine the transit time displayed on the time-display unit. The time-measuring circuit shall be insensitive to operating temperature in the range from 0 to 40°C and voltage changes in the power source of ±15 %.

6.1.4 *Display Unit*—A display unit shall indicate the pulse transit time to the nearest 0.1 µs.

6.1.5 *Reference Bar*—For units that use manual zero-time adjustment, provide a bar of metal or other durable material for which the transit time of longitudinal waves is known. The transit time shall be marked permanently on the reference bar. The reference bar is optional for units that perform automatic zero-time adjustment.

6.1.6 *Connecting Cables*—Where pulse-velocity measurements on large structures require the use of long interconnecting cables, use low-capacitance, shielded, coaxial cables.

6.1.7 *Coupling Agent*—A viscous material (such as oil, petroleum jelly, water soluble jelly, moldable rubber, or grease) to ensure efficient transfer of energy between the concrete and the transducers. The function of the coupling agent is to eliminate air between the contact surfaces of the transducers and the concrete. Water is an acceptable coupling agent if ponded on the surface, or for underwater testing.

7. Procedure

7.1 *Functional Check of Equipment and Zero-time Adjustment*—Verify that the equipment is operating properly and perform a zero-time adjustment.

7.1.1 *Units with Automatic Zero-Time Adjustment*—Follow the manufacturer's instructions for performing zero-time adjustments.

NOTE 8—A reference bar may be used to verify that the zero-time adjustment has been performed correctly.

7.1.2 *Units with Manual Zero-Time Adjustment*—Apply coupling agent to the ends of the reference bar, and press the transducers firmly against the ends of the bar until a stable transit time is displayed. Adjust the zero reference until the displayed transit time agrees with the value marked on the bar.

7.1.3 Check the zero adjustment on an hourly basis during continuous operation of the instrument, and every time a transducer or connecting cable is changed. If zero-time adjustment cannot be accomplished, do not use the instrument until it has been repaired.

7.2 *Determination of Transit Time:*

7.2.1 For testing existing construction, select test locations in accordance with Practice C823, or follow the requirements of the party requesting the testing, whichever is applicable.

7.2.2 For best results, locate the transducers directly opposite each other. Because the beam width of the vibrational pulses emitted by the transducers is large, it is permissible to measure transit times across corners of a structure but with some loss of sensitivity and accuracy. Measurements along the same surface shall not be used unless only one face of the structure is accessible because such measurements may be indicative only of surface layers, and calculated pulse velocities will not agree with those obtained by through transmission (Note 9).

NOTE 9—One of the sources of uncertainty in surface tests is the lengths of the actual travel paths of the pulses. Hence, individual readings are of little value. Surface tests, however, have been used to estimate the depth of a lower quality surface layer by making multiple measurements of transit time with varying distances between the transducers. From the plot of travel time versus spacing, it may be possible to estimate the depth of the lower quality concrete.[5]

7.2.3 Apply an appropriate coupling agent (such as water, oil, petroleum jelly, grease, moldable rubber, or other viscous materials) to the transducer faces or the test surface, or both. Press the faces of the transducers firmly against the surfaces of the concrete until a stable transit time is displayed, and measure the transit time (Note 10). Determine the straight-line distance between centers of transducer faces.

NOTE 10—The quality of the coupling is critically important to the accuracy and maximum range of the method. Inadequate coupling will result in unstable and inaccurate time measurements, and will significantly shorten the effective range of the instrument. Repeat measurements should be made at the same location to minimize erroneous readings due to poor coupling.

8. Calculation

8.1 Calculate the pulse velocity as follows:

$$V = L/T \tag{2}$$

where:

V = pulse velocity, m/s,
L = distance between centers of transducer faces, m, and
T = transit time, s.

9. Report

9.1 Report at least the following information:

9.1.1 Location of test or identification of specimen.

9.1.2 Location of transducers.

9.1.3 Distance between centers of transducer faces, reported to a precision of at least 0.5 % of the distance.

9.1.4 Transit time, reported to a resolution of at least 0.1 µs.

9.1.5 Pulse velocity reported to the nearest 10 m/s.

10. Precision and Bias

10.1 *Precision:*

[5] Chung, H. W., and Law, K. S., "Assessing Fire Damage of Concrete by the Ultrasonic Pulse Technique," *Cement, Concrete, and Aggregates*, CCAGDP, Vol 7, No. 2, Winter, 1985, pp. 84–88.

10.1.1 Repeatability of results have been investigated using devices with CRT displays. It is expected that the repeatability with digital display devices will be better than stated as follows.

10.1.2 Tests involving three test instruments and five operators have indicated that for path lengths from 0.3 to 6 m through sound concrete, different operators using the same instrument or one operator using different instruments will achieve repeatability of test results within 2 %. For longer path lengths through sound concrete, attenuation of the signal will decrease the absolute repeatability of the transit-time measurement, but the longer transit time involved will result in a calculation of velocity having the same order of accuracy.

10.1.3 In the case of tests through badly cracked or deteriorated concrete, the variation of the results are substantially increased. Attenuation is affected by the nature of the deterioration and the resonant frequency of the transducers. Differences between operators or instruments may result in differences in test results as large as 20 %. In such cases, however, calculated velocities will be sufficiently low as to indicate clearly the presence of distress in the concrete tested.

10.2 *Bias*—Bias of this test method has not been determined.

11. Keywords

11.1 concrete; longitudinal stress wave; nondestructive testing; pulse velocity; ultrasonic testing

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue (C597 – 09) that may impact the use of this standard. (Approved April 1, 2016.)

(1) Revised 5.2, 5.9, 6.1.7, 7.2.2, and Note 4 for editorial purposes.
(2) Revised 7.1.1 to reflect the current and future equipment requirements.
(3) Added new Subsection 5.6 and renumbered subsequent sections.
(4) Updated reference in Footnote 3 to newer edition.

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.

Designation: C805/C805M − 18

Standard Test Method for Rebound Number of Hardened Concrete[1]

This standard is issued under the fixed designation C805/C805M; 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 This test method covers the determination of a rebound number of hardened concrete using a spring-driven steel hammer.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.3 *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.*

1.4 *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]

C42/C42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

C125 Terminology Relating to Concrete and Concrete Aggregates

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

E18 Test Methods for Rockwell Hardness of Metallic Materials

2.2 *Other Standard:*[3]

BS EN 13791 Assessment of In-Situ Compressive Strength in Structures and Pre-Cast Concrete Components

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method, refer to Terminology C125.

4. Summary of Test Method

4.1 A steel hammer impacts, with a predetermined amount of energy, a metal plunger in contact with a concrete surface. Either the distance that the hammer rebounds is measured or the hammer speeds before and after impact are measured. The test result is reported as a dimensionless rebound number.

5. Significance and Use

5.1 This test method is applicable to assess the in-place uniformity of concrete, to delineate variations in concrete quality throughout a structure, and to estimate in-place strength if a correlation is developed in accordance with 5.4.

5.2 For a given concrete mixture, the rebound number is affected by factors such as moisture content of the test surface, the type of form material or type of finishing used in construction of the surface to be tested, vertical distance from the bottom of a concrete placement, and the depth of carbonation. These factors need to be considered in interpreting rebound numbers.

5.3 Different instruments of the same nominal design may give rebound numbers differing from 1 to 3 units. Therefore, tests should be made with the same instrument in order to compare results. If more than one instrument is to be used, perform comparative tests on a range of typical concrete surfaces so as to determine the magnitude of the differences to be expected in the readings of different instruments.

5.4 Relationships between rebound number and concrete strength that are provided by instrument manufacturers shall be used only to provide indications of relative concrete strength at different locations in a structure. To use this test method to estimate strength, it is necessary to establish a relationship

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.64 on Nondestructive and In-Place Testing.

Current edition approved Dec. 15, 2018. Published February 2019. Originally approved in 1975. Last previous edition approved in 2013 as C805/C805M – 13a. DOI: 10.1520/C0805_C0805M-18.

[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] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

***A Summary of Changes section appears at the end of this standard**

between strength and rebound number for a given concrete and given apparatus (see Note 1). Establish the relationship by correlating rebound numbers measured on the structure with the measured strengths of cores taken from corresponding locations (see Note 2). At least two replicate cores shall be taken from at least six locations with different rebound numbers. Select test locations so that a wide range of rebound numbers in the structure is obtained. Obtain, prepare, and test cores in accordance with Test Method C42/C42M. If the rebound number is affected by the orientation of the instrument during testing, the strength relationship is applicable for the same orientation as used to obtain the correlation date (see Note 3). Locations where strengths are to be estimated using the developed correlation shall have similar surface texture and shall have been exposed to similar conditions as the locations where correlation cores were taken. The functionality of the rebound hammer shall have been verified in accordance with 6.4 before making the correlation measurements.

NOTE 1—See ACI 228.1R[4] or BS EN 13791 for additional information on developing the relationship and on using the relationship to estimate in-place strength.

NOTE 2—The use of molded test specimens to develop a correlation may not provide a reliable relationship because the surface texture and depth of carbonation of molded specimens are not usually representative of the in-place concrete.

NOTE 3—The use of correction factors to account for instrument orientation may reduce the reliability of strength estimates if the correlation is developed for a different orientation than used for testing.

5.5 This test method is not suitable as the basis for acceptance or rejection of concrete.

6. Apparatus

6.1 *Rebound Hammer,* consisting of a spring-loaded steel hammer that, when released, strikes a metal plunger in contact with the concrete surface. The spring-loaded hammer must travel with a consistent and reproducible speed. The rebound number is based on the rebound distance of the hammer after it impacts the plunger, or it is based on the ratio of the hammer speed after impact to the speed before impact. Rebound numbers based on these two measurement principles are not comparable.

NOTE 4—Several types and sizes of rebound hammers are commercially available to accommodate testing of various sizes and types of concrete construction.

6.1.1 A means shall be provided to display the rebound number after each test.

NOTE 5—Methods of displaying rebound numbers include mechanical sliders and electronic displays. Instruments are available that will store the rebound numbers, which can then be transferred to a computer for analysis.

6.1.2 The manufacturer shall supply rebound number correction factors for instruments that require such a factor to account for the orientation of the instrument during a test. The correction factor is permitted to be applied automatically by the instrument. The manufacturer shall keep a record of test data used as the basis for applicable correction factors.

[4] ACI 228.1R, "In-Place Methods to Estimate Concrete Strength," American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, http://www.concrete.org.

6.2 *Abrasive Stone,* consisting of medium-grain texture silicon carbide or equivalent material.

6.3 *Verification Anvil,* used to check the operation of the rebound hammer. An instrument guide is provided to center the rebound hammer over the impact area and keep the instrument perpendicular to the anvil surface. The anvil shall be constructed so that it will result in a rebound number of at least 75 for a properly operating instrument (see Note 6). The manufacturer of the rebound hammer shall stipulate the type of verification anvil to be used and shall provide the acceptable range of rebound numbers for a properly operating instrument. The anvil manufacturer shall indicate how the anvil is to be supported for verification tests of the instrument, and shall provide instructions for visual inspection of the anvil surface for surface wear.

NOTE 6—A suitable anvil has included an approximately 150 mm [6 in.] diameter by 150 mm [6 in.] tall steel cylinder with an impact area hardened to an HRC hardness value of 64 to 68 as measured by Test Methods E18.

6.4 *Verification*—Rebound hammers shall be serviced and verified annually and whenever there is reason to question their proper operation. Verify the functional operation of a rebound hammer using the verification anvil described in 6.3. During verification, support the anvil as instructed by the anvil manufacturer.

NOTE 7—Typically, a properly operating rebound hammer and a properly designed anvil should result in a rebound number of about 80. The anvil needs to be supported as stated by the anvil manufacturer to obtain reliable rebound numbers. Verification on the anvil does not guarantee that the hammer will yield repeatable rebound numbers at other points on the scale. At the user's option, the rebound hammer can be verified at lower rebound numbers by using blocks of polished stone having uniform hardness. Some users compare several hammers on concrete or stone surfaces encompassing the usual range of rebound numbers encountered in the field.

7. Test Area and Interferences

7.1 *Selection of Test Surface*—Concrete members to be tested shall be at least 100 mm [4 in.] thick and fixed within a structure. Smaller specimens must be rigidly supported. Avoid areas exhibiting honeycombing, scaling, or high porosity. Do not compare test results if the form material against which the concrete was placed is not similar (see Note 8). Troweled surfaces generally exhibit higher rebound numbers than screeded or formed finishes. If possible, test structural slabs from the underside to avoid finished surfaces.

7.2 *Preparation of Test Surface*—A test area shall be at least 150 mm [6 in.] in diameter. Heavily textured, soft, or surfaces with loose mortar shall be ground flat with the abrasive stone described in 6.2. Smooth-formed or troweled surfaces do not have to be ground prior to testing (see Note 8). Do not compare results from ground and unground surfaces. Remove free surface water, if present, before testing.

NOTE 8—Where formed surfaces were ground, increases in rebound number of 2.1 for plywood formed surfaces and 0.4 for high-density plywood formed surfaces have been noted.[5] Dry concrete surfaces give higher rebound numbers than wet surfaces. The presence of surface carbonation can also result in higher rebound numbers.[6] In cases of a thick layer of carbonated concrete, it may be necessary to remove the carbonated layer in the test area, using a power grinder, to obtain rebound numbers that are representative of the interior concrete. Data are not available on the relationship between rebound number and thickness of carbonated concrete. The user should exercise professional judgment when testing carbonated concrete.

7.3 Do not test frozen concrete.

NOTE 9—Moist concrete at 0 °C [32 °F] or less may exhibit high rebound values. Concrete should be tested only after it has thawed. The temperatures of the rebound hammer itself may affect the rebound number. Rebound hammers at –18 °C [0 °F] may exhibit rebound numbers reduced by as much as 2 or 3 units.[7]

7.4 For readings to be compared, the direction of impact, horizontal, downward, upward, or at another angle, must be the same or established correction factors shall be applied to the readings.

7.5 Do not conduct tests directly over reinforcing bars with cover less than 20 mm [0.75 in.].

NOTE 10—The location of reinforcement may be established using reinforcement locators or metal detectors. Follow the manufacturer's instructions for proper operation of such devices.

8. Procedure

8.1 Hold the instrument firmly so that the plunger is perpendicular to the test surface. Record the orientation of the instrument with respect to horizontal to the nearest 45 degree increment. Use a positive angle if the instrument points upward and a negative angle if it points downward with respect to horizontal during testing (see Note 11). Gradually push the instrument toward the test surface until the hammer impacts. After impact, maintain pressure on the instrument and, if necessary, depress the button on the side of the instrument to lock the plunger in its retracted position. Read and record the rebound number to the nearest whole number. Take ten readings from each test area. The distances between impact points shall be at least 25 mm [1 in.], and the distance between impact points and edges of the member shall be at least 50 mm [2 in.]. Examine the impression made on the surface after impact, and if the impact crushes or breaks through a near-surface air void, disregard the reading and take another reading.

NOTE 11—Digital angle gages are available that can be attached to the body of the instrument to allow quick measurement of the angle with respect to horizontal. The recorded orientation would be 0 degrees (horizontal), ±45 degrees (inclined), or ±90 (vertical). For example, if the instrument points vertically down during a test, the angle would be reported as –90 degrees. If the angle is measured to be 55 degrees upward from horizontal, the recorded angle to the nearest 45 degree increment would be +45 degrees.

9. Calculation

9.1 Discard readings differing from the average of ten readings by more than 6 units and determine the average of the remaining readings. If more than two readings differ from the average by 6 units, discard the entire set of readings and determine rebound numbers at ten new locations within the test area.

9.2 If necessary, apply the correction factor to the average rebound number so that the rebound number is for a horizontal orientation of the hammer. Interpolation is permitted if corrections factors are not given for ±45 degrees.

10. Report

10.1 Report the following information, if known, for each test area.

10.1.1 General information:

10.1.1.1 Date of testing,

10.1.1.2 Air temperature and time of testing,

10.1.1.3 Age of concrete, and

10.1.1.4 Identification of test location in the concrete construction and the size of member tested.

10.1.2 Information about the concrete:

10.1.2.1 Mixture identification and type of coarse aggregate, and

10.1.2.2 Specified strength of concrete.

10.1.3 Description of test area:

10.1.3.1 Surface characteristics (trowelled, screeded. formed),

10.1.3.2 If applicable, type of form material used for test area,

10.1.3.3 If surface was ground and depth of grinding,

10.1.3.4 If applicable, curing conditions, and

10.1.3.5 Surface moisture condition (wet or dry).

10.1.4 Hammer information:

10.1.4.1 Hammer identification or serial number, and

10.1.4.2 Date of hammer verification.

10.1.5 Rebound number data:

10.1.5.1 Name of operator,

10.1.5.2 Orientation of hammer during test,

10.1.5.3 On vertical surfaces (walls, columns, deep beams), relative elevation of test region,

10.1.5.4 Individual rebound numbers,

10.1.5.5 Remarks regarding discarded readings,

10.1.5.6 Average rebound number,

10.1.5.7 If necessary, corrected rebound number for a horizontal orientation of the instrument, and

10.1.5.8 If applicable, description of unusual conditions that may affect test readings.

11. Precision and Bias

11.1 *Precision*—The single-specimen, single-operator, machine, day standard deviation is 2.5 units (1s) as defined in Practice C670. Therefore, the range of ten readings should not exceed 12.

11.2 *Bias*—The bias of this test method cannot be evaluated since the rebound number can only be determined in terms of this test method.

[5] Gaynor, R. D., "In-Place Strength of Concrete—A Comparison of Two Test Systems," and "Appendix to Series 193," National Ready Mixed Concrete Assn., TIL No. 272, November 1969.

[6] Zoldners, N. G., "Calibration and Use of Impact Test Hammer," *Proceedings*, American Concrete Institute, Vol 54, August 1957, pp. 161–165.

[7] National Ready Mixed Concrete Assn., TIL No. 260, April 1968.

12. Keywords

12.1 concrete; in-place strength; nondestructive testing; rebound hammer; rebound number

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue, C805/C805M – 13a, that may impact the use of this test method. (Approved Dec. 15, 2018.)

(1) Added 2.2 to reference the new standard mentioned in Note 1.

(2) Modified Note 1 by adding new reference to BS EN 13791.

(3) Renumbered footnotes accordingly.

Japanese & English

コンクリート テスト ハンマー

Concrete Test Hammer

取 扱 説 明 書

Operating Instructions

α HAMMER

Model N－6500

Model D－7000

Model R－7500

MADE IN JAPAN

亀倉精機株式会社
KAMEKURA SEIKI CO.,LTD
JAPAN

目　次 Contents

1. モデルと各部の名称 Models & Part Names

αハンマー測定中
View of α HAMMER in use.

2. はじめに

コンクリートテストハンマーは、硬化コンクリートの表面硬さを測定し、そのコンクリートの圧縮強度を推定する為に用いられます。この試験の特長は、非破壊であり、簡便かつ迅速に行うことが出来ることです。

(1) 動作原理

この試験方法は、コンクリートの圧縮強度と、鋼製のハンマーの反発高さが比例する原理を利用します。

コンクリートテストハンマーは、バネ荷重が与えられた鋼製のハンマー(重錘) を、コンクリート面に接触したプランジャーに打撃させ、ハンマーの反発した距離を、ハンマーと共に、最大値まで移動した指示片の位置を読み取るものです。この指示片位置は、ハンマーの前進全移動距離に対する反発距離の割合で読み取られ、反発度と呼ばれます。そしてこの反発度がコンクリートの表面硬さを表します。

(2) 種類

αハンマーは、次の3機種が用意されています。

1) Model N－６５００　　スケール目盛読み取り式
2) Model D－７０００　　液晶(LCD)デジタル表示式
3) Model R－７５００　　液晶(LCD)デジタル表示式 + プリンター付

(3) 基本仕様

Model N－６５００、D－７０００、R－７５００は、共に次の基本仕様を有します。

1) ハンマー(重錘)質量　375 g
2) ハンマー移動距離　75 mm (最大)
3) 打撃エネルギー　2.207 N・m (水平)
4) 標準アンビル反発度　80±2
5) 適応強度範囲　10.0～70.0 N／mm² (コンクリート圧縮強度)
6) 使用温度範囲　0～40 ℃
7) 電源　単三アルカリ乾電池 1.5V×4ヶ(Model N－６５００を除く)

(4) 付属品

品名	個数	Model		
砥石(コンクリート表面研磨用)	1個	N-6500	D-7000	R-7500
単三アルカリ乾電池	4本	――	D-7000	R-7500
プリンター用感熱紙	5巻	――	――	R-7500
取扱説明書	1冊	N-6500	D-7000	R-7500
収納ケース	1個	N-6500	D-7000	R-7500

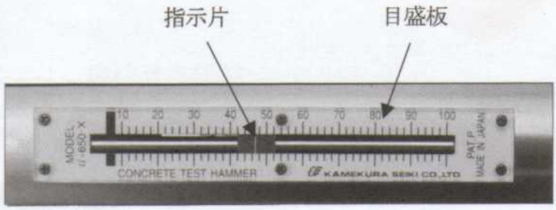
(5) ブリーザー機能　(1 頁写真)

αハンマーに取付られたブリーザーは、テストハンマー内部へのコンクリート粉の侵入を防止し、内部をクリーンに保ちます。その為、一般のコンクリートテストハンマーに比べてメンテナンスサービス期間を 3 倍以上に延長出来ます。

3. Model N－６５００ αハンマーの操作

Model N－６５００は、指示片が示す反発度を、ハウジング側面の目盛板から読み取るタイプです。次に基本的な操作方法を示します。名称等は、1 頁の写真を参照下さい。

◎ 指示部(目盛板)詳細



◎ 操作要領

1) コンクリートテストハンマーのプランジャーを測定面に対して直角を保ちながら、除々に押し込みます。プランジャーがハウジングの内部に完全に入る手前で自動的にハンマーが外れ、衝撃が起こります。

2) 衝撃の後、そのままの姿勢でプッシュボタンを押し込むと、指示片が反発位置に保持されます。　次に、コンクリートテストハンマーを手に取って、目盛板に示された反発度を読み取ります。この時以外は、プッシュボタンを押してはいけません。

3) 反発度の読み取りは、目盛の 1/2、すなわち整数単位で読み取って下さい。

4) 再び測定する時は、プランジャーの先端を何か硬い面か、次の測定面に押し付けると、ハウジングよりプランジャーの先端が抜け出て来ますので、再測定が可能となります。

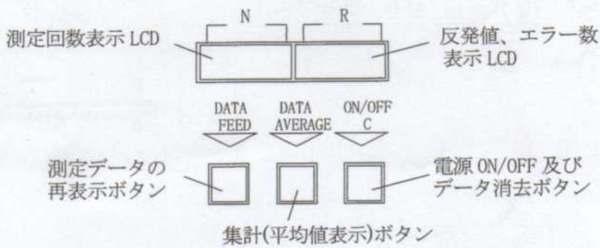
4. Model D－７０００ αハンマーの操作

ModelD－７０００は、ModelN－６５００をベースに反発度を、LCDにデジタル表示します。次に基本的な操作、取扱方法を示します。名称等は、１頁の写真を参照下さい。

◎ 乾電池の交換方法

電池キャップを左に回して取り外します(2ヶ)。乾電池を樹脂ケース側面のイラストのように⊕、⊖を正しく合わせて挿入します。次に、電池キャップを右回しでねじ込み固定して下さい。乾電池は、単三アルカリ乾電池を使用して下さい。

◎ 操作スイッチと表示部



◎ 操作要領　(6頁手順表参照)

1) 収納ケースより取り出した時は、プランジャーがコンクリートテストハンマーの内部に引き込まれたままになっております。プランジャーを引き出す為に、プランジャーの先端をコンクリート面等の硬い面に押し当ててから引くと、プランジャーが伸びて、測定の準備が出来ます。

2) 電源スイッチを入れます。

3) コンクリートテストハンマーのプランジャーを測定面に対して直角に保ちながら、除々に押し込みます。プランジャーがハウジングの内部に完全に入る手前で自動的にハンマーが外れ、衝撃が起こります。

4) 衝撃の後、コンクリートテストハンマーを測定面より手前に引き離すと、液晶表示部から測定回数と反発値を読み取ることが出来ます。

5) 次の測定をする時は、再び上記 3)、4)項と同様の操作をします。

6) 必要な測定回数が終了したら、DATA AVERAGE ボタンを押すと平均値が表示されます。
測定回数は99回まで可能です。
尚、平均値に対して±20%以上外れているデータがある場合、そのデータをエラーとし、そのエラーの個数を表示しますので、エラーの個数だけ追加測定すると、平均値が自動的に表示されます。

7) DATA FEED ボタンを押す度に測定値が、測定順に順次表示されます。

8) 新しい測定をする場合は、電源を一度 OFF にするとデータがクリアされ、新しい測定が可能となります。

9) プッシュボタンは、収納ケースに収納する場合、及び点検調整時等に使用されます。

◎ 収納ケースへの収納

収納ケースに収納する時は、プランジャーをハウジング内に引き込んだ状態を保って収納します。

プランジャーをハウジング内に引き込んだ状態に保つには、何か硬い面にプランジャーの先端を当てて押し込み、衝撃が起こる直前にプッシュボタンを押してプランジャー先端を押し当て面より放して下さい。

◎ D－７０００基本操作手順表

手順	ボタン操作	LCD 表示	備考
1. 電源スイッチ → ON	ON/OFF C	N: （空白）　R: 0 0	
2. 測定 （20 点の測定の場合）		N: 0 1　R: 2 7 N: 0 2　R: 3 1 N: 0 3　R: 2 8 …… N: 2 0　R: 3 0	N : 測定回数 R : 反発値 測定回数は、任意の回数で終了し、集計が出来ます。
3. データ集計スイッチ → ON	DATA AVERAGE	N: A　R: 2 9	全ての測定値が正常な場合 R 窓に平均値を表示し、終了
		N: E　R: 0 2	平均値に対して±20%以上になるデータがある場合、エラーとしてその数を R 窓に表示
4-1. 補充測定 1 回目		N: E　R: 0 1	エラーの残り数を表示
4-2. 補充測定 2 回目		N: A　R: 2 9	補充測定を完了すると自動的に R 窓に平均値を表示し、終了
5. データ再表示 データフィード スイッチ → 順次 ON	DATA FEED DATA FEED …… DATA FEED ⋮	N: 0 1　R: 2 7 N: 0 2　R: 3 1 …… N: E　R: 1 9 …… N: 2 2　R: 2 9	データフィードスイッチを押す度に、測定値が順次エラー値を含んで表示されます。
6. データ集計スイッチ → ON	DATA AVERAGE	N: A　R: 2 9	平均値表示
7. 終了 電源スイッチ → OFF	ON/OFF C	N: （空白）　R: （空白）	データが消去されます。

5. Model R－７５００ αハンマーの操作

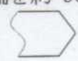
Model R－７５００は、Model N－６５００をベースに、反発度をLCDにデジタル表示すると同時に、熱転写プリンターで測定値、エラー値、平均値及び打撃角度をプリントアウトする機能を有します。次に基本的な操作、取扱方法を示します。名称等は、1頁の写真を参照下さい。

◎ 乾電池の交換方法

電池キャップを左に回して取り外します(2ヶ)。乾電池を樹脂ケース側面のイラストのように⊕、⊖を正しく合わせて挿入します。次に、電池キャップを右回しでねじ込み固定して下さい。乾電池は、単三アルカリ乾電池を使用して下さい。

◎ 記録紙の取付

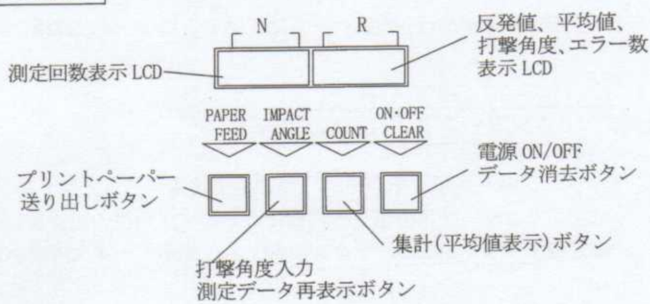
1) 記録紙(ロール紙)の先端を約 90°～120° の三角形状に切断します。



2) 本体のプリンターカバーを開け、プリンターとプリント基板の間の隙間に記録紙の先端を充分奥まで差し込み、PAPER FEED ボタンを押すと、記録紙が送り出されます。

3) 送り出された記録紙を、プリンターカバーの記録紙用スリットに通してプリンターカバーを閉じ、スライドロックボタンでロックします。

◎ 操作スイッチと表示部



◎ 操作要領(プリンター使用)　(9頁の手順表参照)

1) 収納ケースより取り出した時は、プランジャーがコンクリートテストハンマーの内部に引き込まれたままになっております。プランジャーを引き出す為に、プランジャーの先端をコンクリート面等の硬い面に押し当ててから引くと、プランジャーが伸びて測定の準備が出来ます。

2) プリンタースイッチを [PRINT] 側にし、電源スイッチを入れます。

3) 打撃角度入力ボタンで打撃角度を0° 90° −90° より選択します。選択しない場合は、0° 選択です。 角度の選択は、メモとして記録紙に記録されるものです。

4) コンクリートテストハンマーのプランジャーを測定面に対して直角に保ちながら、除々に押し込みます。プランジャーがハウジングの内部に完全に入る手前で自動的にハンマーが外れ、衝撃が起こります。

5) 衝撃後、コンクリートテストハンマーを測定面より手前に引き離すと、液晶表示部から測定回数と反発値を読み取ることが出来ます。又この時、プリンターがこの結果を印字します。

6) 次の測定をする時は、再び上記 4)、5)項と同様の操作をします。

7) 必要な測定回数が終了したら、集計 [COUNT] ボタンを押すと、打撃角度と平均値を印字します。測定回数は、99 回まで可能です。
尚、平均値に対して±20%以上外れているデータがある場合、そのデータをエラーとし、そのエラーの個数を表示しますので、エラーの個数だけ追加測定すると、平均値と打撃角度が自動的に印字されます。

8) 新しい測定をする場合は、電源を一度 OFF にするとデータがクリアされ、新しい測定が可能となります。

9) [PAPER FEED] ボタンを押すと記録紙が送り出されます。印字が全て見える様になったら、記録紙を切断します。

10) プッシュボタンは、収納ケースに収納する場合、及び点検、調整時等に使用されます。

◎ プリンターを使用しない場合

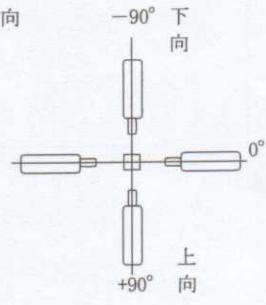
プリンタースイッチを [DIGI] 側にして使用すると、プリンターは動作しません。測定は、プリンター使用の場合と同様に行います。角度の選択及び、集計は出来ません。
測定後 [IMPACT ANGLE] ボタンを押すと、測定データを再表示させることが出来ます。

◎ 収納ケースへの収納

収納ケースに収納する時は、プランジャーをハウジング内に引き込んだ状態を保って収納します。

プランジャーをハウジング内に引き込んだ状態に保つには、何か硬い面にプランジャーの先端を当てて押し込み、衝撃が起こる直前にプッシュボタンを押してプランジャー先端を押し当て面より放して下さい。

◎ R－7500基本操作手順表(プリンター使用)

手順	ボタン操作	LCD 表示	備考
1. プリンタースイッチ → PRINT 側に		N: (空白) R: (空白)	PRINT ■□ DIGI ←
2. 電源スイッチ → ON	ON/OFF CLEAR	N: (空白) R: 0 0	
3. 打撃方向選択 選択をせず次に進むと 0°の選択となる。	IMPACT ANGLE IMPACT ANGLE IMPACT ANGLE	N: (空白) R: 9 0 － 9 0 (空白) 0	打撃方向  水平
4. 測定 (20 打点の測定の場合)		N R 0 1 2 7 0 2 3 1 ------ 2 0 3 0	N：測定回数 R：反発値 測定回数は、任意の回数で終了し、集計が出来ます。 プリンターが 1 打点毎に測定値を印字
5. データ集計スイッチ → ON	COUNT	N: (空白) R: 0 0 ------ E 0 2	全ての測定値が正常な場合、プリンターが平均値と打撃角度を印字 ------ 平均値に対して±20%以上になるデータがある場合、エラーとしてその数を R 窓に表示
6-1. 補充測定 1 回目		N: E R: 0 1	エラーの残りを表示
6-2. 補充測定 2 回目 ------ 6-3. 次の設定 → 3 項へ		N: (空白) R: 0 0	補充測定を完了すると自動的に平均値と打撃角度を印字し、終了 ------ 集計が終了しているとデータはクリアされていますので、そのまま次の測定が出来ます。

手順	ボタン操作	LCD 表示	備考	
7. 記録紙送り出し	PAPER FEED	N: R: 0 0		印字例 R 01 29 R 02 29 R 03 28 R 04 29 R 05 28 R 06 28 R 07 28 R 08 28 R 09 15 R 10 15 ER 09 15 ER 10 15 Ro R 11 28 R 12 28 AVERAGE 28. 3 ANGLE 0
8. 終了 電源スイッチ → OFF	ON/OFF CLERA		データが消去されます。	

6. 試験要領

(1) 測定箇所の選定

1) 形枠に接している平面を選び、多孔質の面、凹凸のある面は避ける。
2) 出来るだけ乾燥した滑らかで垂直な面を選ぶ。
3) 厚さは、10cm 以上、角柱の場合は、15cm 角以上のものとする。

(2) 表面の準備

1) 必要な回数(9～20 点)の測定が行える充分な範囲を確保して下さい。
2) 平滑でない面は、グラインダー等で平坦にして下さい。
3) モルタル面は取り除く必要があります。
4) 6 ヶ月以上の古い面は、5～6mm 削り取って下さい。
5) 測定面は、付属の砥石でわずかな凹凸を取り除いて下さい。
6) 出来れば濡れている場合、24 時間以上乾燥させて下さい。

(3) 測定

1) 打撃数は、日本では一般に 20 打撃の反発度の平均値を、その部位の反発度とします。又 JIS A 1155 による測定要領に従う場合は、9 打撃の平均で良いことになっています。
(参考 ASTM-C805　7～10 打撃の平均　　BS4408　9～25 打撃の平均)

2) 打撃は、同じ部位を繰り返してはいけません。2.5～3cm 以上離れた場所、又、縁より 5cm 以上離れた場所を打撃します。

3) クボミ部、あるいは骨材がむき出しの部分は測定を避けて下さい。

4) 測定は、テストハンマーを測定面に正しく直角に保ちながらゆっくりと押し込むと、自動的に打撃が発生し測定が行われます。

5) 3 ヶ月以上使用しなかった場合、あるいは寒冷時には、測定前に約 10 回の試し打ちを行って下さい。

6) 測定値の読みは、整数値(2 桁)で読み取ります。

(4) 平均値の算出

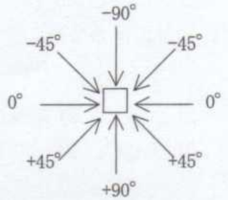
必要打撃数の測定後は、その測定値の平均値を算出します。日本では、平均値の±20%を外れた測定値は、その値を捨てそれに代わるデータを測定、補充して平均値を再計算します。

この平均値をもってその測定部位の反発値とします。

(5) 打撃角度補正

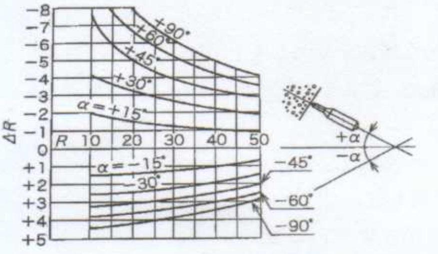
テストハンマーの測定が水平面や傾いた面で行われた場合、反発度の補正が必要です。反発度の補正は日本では、一般に下のグラフの値を用いて、次の式で計算します。

又、DIN1048(ドイツ)規格では、右表の補正値が用いられてます。



$R=R_o+\triangle R$　　R_o　測定反発度

$\triangle R$　角度補正値



打撃角度補正 (JIS A 1155 参考値)

Ro 反発度	角度補正値 △R (DIN 1048)			
	+90°	+45°	-45°	-90°
20	−6	−4	+2	+3
30	−5	−3	+2	+3
40	−4	−3	+2	+2
50	−3	−2	+1	+2
60	−2	−2	+1	+2

(6) 表面湿潤補正

コンクリートの測定面が濡れている場合は、測定値に次の値を加算します。

コンクリートが湿って打撃点が黒色になる場合

$\triangle R_w=+3$

コンクリート表面が完全に濡れている場合

$\triangle R_w=+5$

(7) 圧縮強度の推定

1) 反発値よりコンクリートの圧縮強度を推定する場合、日本では普通ポルトランドセメントに対して一般に次の式が用いられます。

$$F(N/mm^2)=0.098\times(-184+13R)$$

(日本材料学会式 円柱体試験片に換算)

2) 右の早見表は、スイス連邦材料試験場のもので、多くの国々で使用されています。

円柱体圧縮強度 F(N/mm²)

R	N/mm²				
	-90°	-45°	0°	+45°	+90°
20	12.3	11.3	—	—	—
21	13.2	12.3	—	—	—
22	14.2	13.2	10.8	—	—
23	15.7	14.2	11.8	—	—
24	16.7	15.7	12.7	—	—
25	17.7	16.7	13.7	9.8	—
26	19.4	18.1	15.5	11.3	—
27	20.6	19.6	16.2	12.7	10.3
28	21.6	20.6	17.7	13.7	11.8
29	23.3	21.6	18.6	14.7	13.5
30	24.5	23.3	20.6	16.7	14.2
31	25.5	24.5	21.6	17.7	15.7
32	27.5	26.0	23.3	18.6	16.7
33	28.4	27.5	24.5	20.6	18.6
34	30.4	28.4	25.5	21.6	19.6
35	31.4	30.4	27.5	23.3	21.4
36	33.3	31.4	28.4	24.5	22.6
37	34.3	33.3	30.4	26.0	24.0
38	36.3	34.3	31.4	27.5	25.5
39	37.3	36.3	33.3	29.4	27.5
40	39.2	37.3	34.3	30.4	28.9
41	40.2	39.2	36.3	32.4	30.4
42	41.7	40.7	37.3	33.8	31.9
43	43.1	42.2	39.2	35.3	33.3
44	45.1	44.1	41.2	37.3	35.3
45	46.1	45.1	42.2	38.7	36.8
46	48.1	47.1	44.1	40.2	38.2
47	49.0	48.5	45.6	42.2	40.2
48	51.0	50.0	47.1	43.6	42.2
49	53.0	51.5	49.0	45.1	43.6
50	53.9	53.0	50.5	47.1	45.1
51	55.9	54.9	52.0	49.0	47.1
52	56.9	55.9	53.9	50.5	49.0
53	58.8	57.9	55.4	52.0	51.0
54	↑58.8	↑58.8	56.9	53.9	52.0
55	↑58.8	↑58.8	58.8	55.9	53.9

◎スイス連邦材料試験所提供

(8) 材令補正

打設日からの経過日数により、下表の材令係数を用いて修正が行われます。

(DIN 4240 より)

材令 n(日)	10	20	28	50	100	150	200	300	500	1000	3000
α_n	1.55	1.12	1.00	0.87	0.78	0.74	0.72	0.70	0.67	0.65	0.63

α_n 材令係数

$$Fc(N/mm^2) = F \times \alpha_n$$

(9) 測定結果のまとめ例

基準アンビル値 Ra	アンビル測定値					平均値 Rao
80	80	81	81	80	81	80.6

ブロック No.	測定反発度				平均値 Ro	方向補正値 ΔR	湿潤補正 ΔRw	基準反発度 R	材令係数 α_n	推定圧縮強度 Fc(N/mm²)	備考
橋梁 1	29	28	29	29		-90°	乾燥		28 日		
	28	~~36~~	29	28							
	28	~~35~~	28	29							
					28.5	ΔR=3.9	ΔRw=0	32.4	α_n=1	23.2	

$$R = Ro \times \frac{Ra}{Rao} + \triangle R + \triangle Rw \quad \text{換算式} \quad Fc = 0.098 \times (-184 + 13R) \times \alpha_n$$

(10) 報告項目

報告書には、次の項目を報告します。

1) 測定日
2) 測定値と推定圧縮強度
3) テストハンマーの機種、製造日（検定日)、製造社名、製造番号
4) 構造物の種類、部材、測定部位
5) コンクリートの種類、配合情報

7. テストアンビル校正

(1) テストアンビル

1) 弊社で反発値が R=80 を示すテストアンビルを製造、販売しており、このテストアンビルは、質量 約 16kg の合金鋼で作られ、コンクリートテストハンマーが正しく機能しているかチェックする為に使用されます。

2) テストハンマーの打撃測定回数が 1500 回毎に、又は、6 ヶ月毎に、テストアンビルを用いて検定することを推奨いたします。

(JIS A 1155 の測定では、500 回打撃毎に検定が必要です。)

(2) テストアンビルの使用法

1) テストアンビルは、コンクリート床の様な固く水平で、平坦な場所に置きます。

2) テストアンビルのガイドに沿ってコンクリートテストハンマーの先端を挿入し、コンクリートの測定と同様に測定を行い、反発値を 5〜10 回読み取り、その平均値を算出します。

3) テストアンビルの反発値は 80±2 を示さなければなりません。80 を外れている場合は、次の式を適応することにより、より高精度の反発値を得ることが出来ます。

アンビルテスト

$$R = R_o \frac{80}{R_a}$$

R_o コンクリート測定値

R_a アンビル測定値

4) この式は、アンビルの反発値が 74〜84 の間で有効です。アンビル値がこの値を外れている場合は、コンクリートテストハンマーの修理、点検を行う必要があります。

8. 保守及び注意事項

(1) αハンマーは、常にコンクリートミスト等を取り除いて清浄にし、収納ケースに保管して下さい。

(2) αハンマーは、6000 打撃又は一年間を超えた場合、点検、調整を推奨します。

(3) 測定値が異常と判断される場合、あるいはテストハンマーに損傷が発見された場合、修理が必要です。調整、修理は、専門知識と技術が必要です。販売店に依頼して下さい。

(4) プランジャーの先端を人体部分に向けて使用しないで下さい。直角にゆっくり押し込み操作をして下さい。斜めに打撃するとプランジャーが滑ったり飛び出したりして危険です。

(5) 落下、衝撃、振動等を与えないで下さい。

(6) 分解はしないで下さい。

(7) 測定時に、最も重要な点は、測定面にテストハンマーが直角になっていることと、ハウジングを徐々に押し込んで衝撃を発生させることです。

以上

2. General Information

The concrete test hammer is used to measure the surface hardness of any concrete mass. The compressive strength of nearly concrete mass is determined by results of tests made with the instrument. The test is nondestructive therefore it is a simple, speedy and convenient method.

(1) Operating Principle

The test hammer utilizes the principle that the rebound of a steel hammer is proportional to the compressive strength of the concrete.

The concrete test hammer consisting of spring-loaded steel hammer which when released strikes a steel plunger in contact with the concrete surface. Then the rebound distance of the steel hammer from the steel plunger is measured in a linear scale attached to the frame of the instrument. The scale is calibrated to express rebound distance as a percent of the full distance the hammer travels prior to impact. This rebound distance value "R" is called the rebound number.

The rebound number gives an indication of the surface hardness of the concrete mass.

(2) Models of α HAMMAER

There are three models of the α HAMMER.

1) Model N－６５００　Indication on the Graduated Scale
2) Model D－７０００　Indication in the LC Display
3) Model R－７５００　Indication in the LC Display & with Printer

(3) Basic Specifications

Basic specifications of Model N－６５００,D－７０００,R－７５００ are as follows.

1) Weight of Hammer Mass　375 g
2) Hammer Travel Distance　75 mm　(full)
3) Impact Energy　2.207 N・m (horizontal)
4) Anvil Standard Value　80±2
5) Measuring Range　10～70 N/mm² (compressive strength)
6) Operating Temperature　0～40 ℃
7) Batteries　LR-6(Alkaline) 1.5V 4 Round Cells (except Model N－６５００)

(4) Standard Accessories

Description	Q'ty	Model		
Abrasive Stone	1	N-6500	D-7000	R-7500
Alkaline Batteries LR6	4	――	D-7000	R-7500
Recording Papers	5rolles	――	――	R-7500
Instruction Manual	1	N-6500	D-7000	R-7500
Carrying Case	1	N-6500	D-7000	R-7500

(5) Breather Unit (See the page 1 illustration.)

The breather unit on α Hammer prevents ingress of concrete-dust, and keeps the α Hammer clean. Accordingly we are able to prolong its service intervals threefold over.

3. Operation Model N-6500 α HAMMER

The rebound number of Model N-6500 can be indicated with the scale on the housing. The basic operation is explained as follows. The part names are referred to the page 1 illustrations.

◎ Vew of the Scale (Graduated Plate)

Reading pointer Graduated plate

◎ How to Handle

1) Put the plunger against the concrete surface to be tested at right angles. Then press your instrument against the surface. Just before the plunger disappears completely in the housing the hammer mass is released and the impact is come out.

2) Don't touch the push-button as yet. After the impact is completed push the push-button immediately to retain the plunger in the housing and the reading pointer is retained on the reading point. Then take up your instrument, you are able to read the rebound number.

3) The rebound number should be read the half scale unit on graduated plate. In other words, record it to two significant figures.

4) Press the plunger head on any hard surface to eject it until it is released. And you will be able to carry out another test.

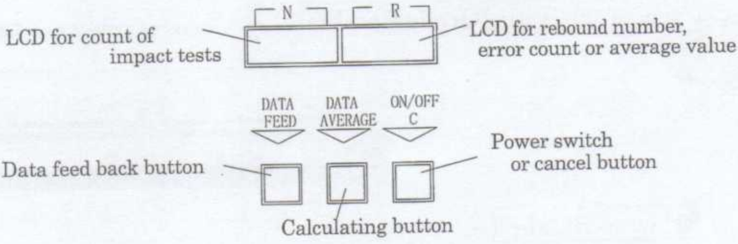
4. Operation Model D-7000 α HAMMER

The Model D-7000 α Hammer is based upon the Model N-6500. The rebound number of Model D-7000 can be indicated in digital figures in the LC Display. The basic operation is explained as follows. The part names are referred on the page 1 illustrations.

◎ Exchanging the Batteries

Unscrew the tow battery caps on your instrument to the left-hand and remove them. Take off the used batteries. Then insert the new batteries (2 cells) into the each holder in accordance with the illustrations (⊕,⊖) on your instrument. Then set the battery caps. The alkaline LR6 batteries should be used.

◎ Vew of the Operating Switches & Display



◎ How to Operate

See The Page 20 (Basic Operation Table)

1) When the α Hammer is in the carrying case, the plunger head is practically inside the housing. To eject the plunger press lightly its head on any hard surface, and the plunger is released. By removing the α Hammer from pressed surface, the plunger will slide out of the housing by itself. Then you will be able to test.

2) Push the ON/OFF button.

3) Rest the plunger head at right angles against the concrete surface to be tested. Press and press the α Hammer in a continuous, and just before the plunger disappears completely in the housing the hammer mass is released and impact is come out.

4) After impact, remove the α Hammer you will read the number of impacts & rebound number on the LCD.

5) To carry out another test repeat the operations indicated in point 3) & 4).

6) When the impact number you need is finished to carry out, push the DATA AVERAGE button and average value is displayed with symbol "A" in the LCD. The number of impacts that you can carry out is 99 impacts maximum. But you can finish the arbitrary number of impacts. If the some value is displayed with symbol "E", repeat the impact tests but only impacts of "E" number at a near area to get consistent data. And average value is displayed automatically. Symbol "E" and number mean the number of errors. The data deviated more than ±20% from the average are the error.

7) Every time you push the DATA FEED button, DATA is fed back in the LCD according to measuring order.

8) To carry out the new test all memory contents must be canceled by pushing the ON/OFF button.

9) Don't handle the push button that is behind your instrument except storing and checking the α Hammer.

◎ How to store into the Carrying Case

Press lightly the plunger head on any hard surface, and just before the hammer mass released, push the Push Button. Then remove the α Hammer while the push button is pushed.

The plunger head is kept practically inside the housing. Now you will be able to store α Hammer into the carrying case.

◎ Basic Operation Table D-7000 α HAMMER

Process	Switching	LC Display	Remarks
1. Power switch → ON	ON/OFF C	N: (blank) R: 0 0	
2. Measurment (Case of 20 impacts)		N: 0 1 R: 2 7 N: 0 2 R: 3 1 N: 0 3 R: 2 8 …… N: 2 0 R: 3 0	N : Count of impact R : Rebound number You can measure any number of times and finish to measure using the DATA AVEREGE button.
3. Calculating (DATA AVERAGE) button → ON	DATA AVERAGE	N: A R: 2 9	If all data are correct and the test is finished. The average value is displayed with symbol "A"
		E 0 2	The data deviated more than ±20% from the average value are error data. The number of error data is displayed with symbol "E".
4-1. Additional test (first inpact)		N: E R: 0 1	Only the displayed number repeat the impact tests.
4-2. Additional test (second impact)		A 2 9	When additional tests are finished average value is automatically displayed with symbol "A". And the test is finished.
5. Data feed-back Data Feed back button → on and on	DATA FEED DATA FEED DATA FEED ⋮	N: 0 1 R: 2 7 0 2 3 1 …… E 1 9 …… 2 2 2 9	Every time you push the DATA FEED button, each data is fed back in the LCD. The error data is fed back, too.
6. Calculating button → ON	DATA AVERAGE	N: A R: 2 9	Average value is displayed.
7. Finish Power switch → OFF	ON/OFF C	N: (blank) R: (blank)	All memory contents are canceled.

5. Operation Model R-7500 α HAMMER

The Model R-7500 α Hammer is based upon the Model N-6500, but is equipped with a thermal printer and LC Display. The rebound number of ModelR-7500 can be indicated in digital figures in the LC Display, what is more the impact number, rebound number, bar graph, average value, impact angle (up, down, horizontal) and error data are printed with the printer. The basic operation is explained as follows. The part names are referred on the page 1 illustrations.

◎ Exchanging the Batteries

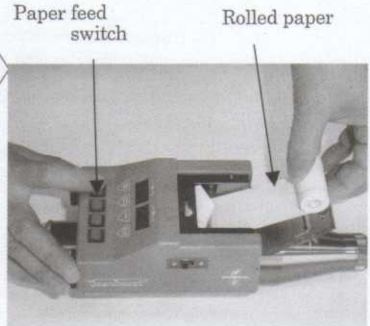
Unscrew the tow battery caps on your instrument to the left-hand and remove them. Take off the used batteries. Then insert the new batteries (2 cells) into the each holder in accordance with the illustrations (⊕,⊖) on your instrument. Then set the battery caps. The alkaline LR6 batteries should be used.

◎ Installing the Recording Paper

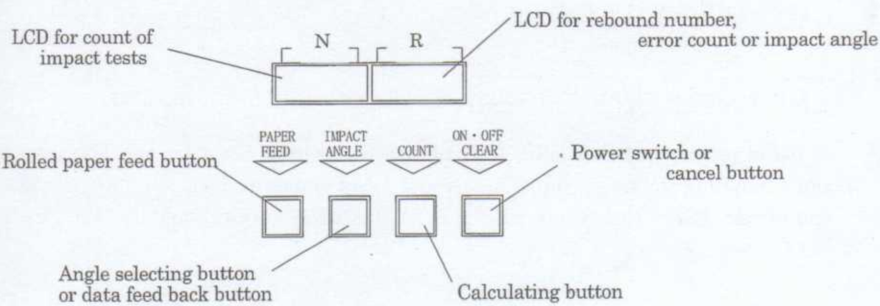
1) Cut off the tip of rolled paper at 90° ~120°

2) Open the printer cover. Then insert the tip of rolled paper into the slit which is between the printer and the PCB. While thrusting the rolled paper, push the PAPER FEED button until the tip of paper comes out from another slit.

3) Let the paper through the slit of printer cover. Then shut and lock the printer cover.



◎ Vew of the Operating Switches & Display



◎ How to Operate

See The page 23 (Basic Operation Table)

1) When the α Hammer is in the carrying case, the plunger head is practically inside the housing. To eject the plunger press lightly its head on any hard surface, and the plunger is released. By removing the α Hammer from pressed surface, the plunger will slide out of the housing by itself. Then you will be able to test.

2) Shift the printer switch to PRINT-side then push the ON/OFF button.

3) Select the impact angles (0° 90° −90°) with the Impact Angle button. In case of 0° (horizontal) you may pass this selection. Impact angle is printed on the thermal paper along with another data at end of test.

4) Rest the plunger head at right angles against the concrete surface to be tested. Press and press the α Hammer in a continuous and just before the plunger disappears completely in the housing the hammer mass is released and impact is come out.

5) After impact, remove the α Hammer you will read the number of impacts & rebound number in the LCD. At the same time the number of impacts & rebound number are printed automatically.

6) To carry out another test, repeat the operations indicated in point 4) & 5).

7) When the impact number you need is finished to carry out, push the COUNT button and average value is printed. The number of impacts that you can carry out is 99 impacts maximum. But you can finish the arbitrary number of impacts. If the some value is displayed with symbol "E", repeat the impact tests but only impact of "E" number at a near area to get consistent data, and average value and another data are printed automatically. Symbol "E" and number mean the error count. The data deviated more than ±20% from the average are the error.

8) To carry out the new test all memory contents must be canceled by pushing the ON/OFF button.

9) Push the PAPER FEED button until end of the data come out through the slit of the printer cover, then cut the rolled paper.

10) Don't handle the push button that is behind your instrument except storing and checking the α Hammer.

◎ Operation without Printing

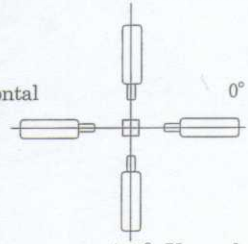
If the printer switch is shift to DIGI-side the printer doesn't work. You may test same handling of using printer. You cannot select angles and not compute averages at end of test. Every time you push the INPACT ANGLE button, the data is fed back in the LC Display.

◎ How to store into the Carrying Case

Press lightly the plunger head on any hard surface, and just before the hammer mass released, push the push button. Then remove the α Hammer while the push button is pushed.

The plunger head is kept practically inside the housing. Now you will be able to store α Hammer into the carrying case.

◎ Basic Operation Table R-7500 α HAMMER (using printer)

Process	Switching	LC Display	Remarks
1. Printer switch shift to PRINT		N: [ ] R: [ ]	PRINT ▭ DIGI ←
2. Power switch → ON	ON/OFF CLEAR	N: [ ] R: [0 0]	
3. Selecting the impact angle	IMPACT ANGLE IMPACT ANGLE IMPACT ANGLE	N: [ ] R: [9 0] [—] [9 0] [ ] [0]	Direction of impact −90° Downwards Horizontal 0°  +90° Upwards
4. Masurment (case of 20 impacts)		N: [0 1] R: [2 7] [0 2] [3 1] ------ ------ ------ [2 0] [3 0]	N : Count of impact R : Rebound number You can measure any number of times and finish to measure using the COUNT button. Data is printed out automatically one by one impact.
5. Calculating (Count) button → ON	COUNT	N: [ ] R: [0 0]	If all data are correct the average value and impact angle is printed on the rolled paper. Then the test is finished.
		[E] [0 2]	The data deviated more than ±20% from the average value are the error data. The number of error data is displayed with symbol "E".
6-1. Additional test First impact		N: [E] R: [0 1]	Only the displayed number repeat the impact tests.
6-2. Additional test Second impact		N: [ ] R: [0 0]	When additional tests are finished average value and impact angle is automatically printed on the rolled paper.
6-3. Next measurment → Go to 3. column			Just then the average value & impact angle are printed, all memory contents is canceled. You can carry out the another test.

Process	Switching	LC Display	Remarks	
7. Feeding paper	PAPER FEED	N: [ ] R: [0 0]		A sample of print R 01 29 R 02 29 R 03 28 R 04 29 R 05 28 R 06 28 R 07 28 R 08 28 R 09 15 R 10 15 ER 09 15 ER 10 15 Ro R 11 28 R 12 28 AVERAGE 28. 3 ANGLE 0
8. Finish Power switch → OFF	ON/OFF CLERA	[ ] [ ]	All memory contents are canceled.	

6. Method of Testing a Structure

(1) Selection of Test Area

1) Testing should be conducted on flat and smooth surfaces of the concrete structures which were encased in a form. Avoid to test on honeycombs, porous or rough area.
2) Select a smooth, clean and dry surface. If possible, test vertical surfaces.
3) Walls should be more than 10cm thick and columns should be more than 15cm.

(2) Surface Preparation

1) A test area must be at least as large as to impact numbers (9~20 point) you need.
2) On irregular surfaces remove using an electric grinding wheel.
3) Any plaster or coating covering the concrete should be removed.
4) Concretes over 6 months old may require grinding to a depth 5~6m/m.
5) Slightly uneven surfaces can be removed with the abrasive stone that is supplied with the instrument.
6) The wet surface should be dried for 24h prior to testing.

(3) Testing Procedure

1) In Japan impact test is generally carried out at 20 points of the prepared area. Take the average value R of 20-hammer readings. This average value is called rebound number.

Number of impact points that is recommended	JIS A 1155	9	points
	ASTM-C805	7~10	points
	BS4408	9~25	points

2) For each impact of the hammer, move the instrument about 2.5~3cm to avoid more than one impact at a given point. The point of impact should be at least 5cm away from any edge.

3) Avoid to impact at porous point or large pieces of aggregate.

4) Firmly hold the instrument in a position that allows the plunger to strike perpendicularly to the surface to be tested. Gradually increase the pressure on the plunger until the hammer impacts. Then you will be record the rebound number.

5) Carry out a trial test about 10 impacts on any heard surface, when it is cold day or instrument has not used 3 month over.

6) Record the rebound number to two significant figures.

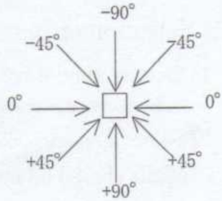
(4) Calculation of Average Value

After having finished the tests, calculate the average value from recorded DATA. Take out the error data that deviated more than ±20% from the average value. The error data are to be eliminated and to be replaced by a further impact test and calculate the average again. This average value is the rebound number.

(5) Correction for Impact Direction

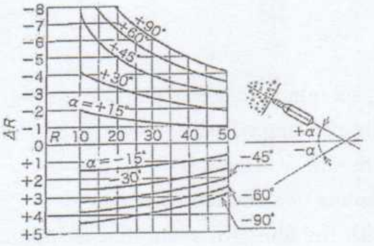
When using the α Hammer on inclined of horizontal surfaces, the rebound value must be corrected as per the following formula.

The correction values are following graph (JIS) or table (DIN).



$R = R_o + \triangle R$ R_o Rebound Value tested

$\triangle R$ Correction Value



(JIS A 1155)

△R Correction value for inclination angle

R_o	△R DIN 1048 correction value for inclination angle			
	+90°	+45°	−45°	−90°
20	−6	−4	+2	+3
30	−5	−3	+2	+3
40	−4	−3	+2	+2
50	−3	−2	+1	+2
60	−2	−2	+1	+2

(6) Correction for Moisture Condition of Surface

Following value (△Rw) should be added to rebound value tested with the α Hammer.

When the impact points tested change to dark gray color owing to surfaces are slightly wetting ------------ △Rw=+3

When the surfaces are thoroughly wetting ------------ △Rw=+5

(7) Determination of Compressive Strength

1) In Japan the following formula is widely used to estimate the compressive strength of concrete made of Portland cement.

$$F\,(N/mm^2) = 0.098 \times (-184 + 13R)$$

(cylinder compressive strength)

2) Cylinder compressive strength table on this page and cube compressive strength tables on the last page are presented by Swiss Federal material testing Institute. These tables are used all over the world.

Cylinder compressive strength table (N/mm²)

R	N/mm²				
	−90°	−45°	0°	+45°	+90°
20	12.3	11.3	—	—	—
21	13.2	12.3	—	—	—
22	14.2	13.2	10.8	—	—
23	15.7	14.2	11.8	—	—
24	16.7	15.7	12.7	—	—
25	17.7	16.7	13.7	9.8	—
26	19.4	18.1	15.5	11.3	—
27	20.6	19.6	16.2	12.7	10.3
28	21.6	20.6	17.7	13.7	11.8
29	23.3	21.6	18.6	14.7	13.5
30	24.5	23.3	20.6	16.7	14.2
31	25.5	24.5	21.6	17.7	15.7
32	27.5	26.0	23.3	18.6	16.7
33	28.4	27.5	24.5	20.6	18.6
34	30.4	28.4	25.5	21.6	19.6
35	31.4	30.4	27.5	23.3	21.4
36	33.3	31.4	28.4	24.5	22.6
37	34.3	33.3	30.4	26.0	24.0
38	36.3	34.3	31.4	27.5	25.5
39	37.3	36.3	33.3	29.4	27.5
40	39.2	37.3	34.3	30.4	28.9
41	40.2	39.2	36.3	32.4	30.4
42	41.7	40.7	37.3	33.8	31.9
43	43.1	42.2	39.2	35.3	33.3
44	45.1	44.1	41.2	37.3	35.3
45	46.1	45.1	42.2	38.7	36.8
46	48.1	47.1	44.1	40.2	38.2
47	49.0	48.5	45.6	42.2	40.2
48	51.0	50.0	47.1	43.6	42.2
49	53.0	51.5	49.0	45.1	43.6
50	53.9	53.0	50.5	47.1	45.1
51	55.9	54.9	52.0	49.0	47.1
52	56.9	55.9	53.9	50.5	49.0
53	58.8	57.9	55.4	52.0	51.0
54	↑58.8	↑58.8	56.9	53.9	52.0
55	↑58.8	↑58.8	58.8	55.9	53.9

◎Zurich Standard ※"↑" MEANS "OVER"

(8) Factors of Age

If the age of concrete is not 28days, compressive strength should be corrected as per following table.

Quotation from DIN 4240

Ages n (days)	10	20	28	50	100	150	200	300	500	1000	3000
α_n	1. 55	1. 12	1. 00	0. 87	0. 78	0. 74	0. 72	0. 70	0. 67	0. 65	0. 63

α_n = correcting factor of ages

$$F_c\ (N/mm^2) = F \times \alpha_n$$

(9) Sample Chart for test report

<table>
<tr><th>Nominal value of Anvil
Ra</th><th colspan="5">Readings on the Anvil</th><th>Average value
Rao</th></tr>
<tr><td rowspan="2">80</td><td>80</td><td>81</td><td>81</td><td>80</td><td>81</td><td rowspan="2">80. 6</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table>

<table>
<tr><th>Position of test area</th><th colspan="4">Readings of the test area</th><th>Average of readings
Ro</th><th>Correction factor for impact angle
ΔR</th><th>Correction factor for moisture condition
ΔRw</th><th>Basic rebound number
R</th><th>Correction factor for concrete age
α_n</th><th>Compressive strength (estimation)
Fc (N/mm²)</th><th>Remarks</th></tr>
<tr><td rowspan="5">Bridge column 1.</td><td>29</td><td>28</td><td>29</td><td>29</td><td rowspan="5">28. 5</td><td rowspan="2">-90°</td><td rowspan="2">Dry</td><td rowspan="5">32. 4</td><td rowspan="2">28days</td><td rowspan="5">23. 2</td><td rowspan="5"></td></tr>
<tr><td>28</td><td>~~36~~</td><td>29</td><td>28</td></tr>
<tr><td>28</td><td>~~35~~</td><td>28</td><td>29</td><td rowspan="3">ΔR=3. 9</td><td rowspan="3">ΔRw=0</td><td rowspan="3">α_n=1</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

$$R = R_o \times \frac{R_a}{R_{ao}} + \triangle R + \triangle R_w$$

Formula for determination of strength

$$F_c = 0.098 \times (-184 + 13R) \times \alpha_n$$

(10) Items for Report

The results of test should be report as follows.

1) The date of test
2) Data of readings & estimation of compressive strength
3) Device used (model, maker, product No., Product date)
4) Description of structure (test area etc.)
5) Description of concrete

7. Calibration with Testing Anvil

(1) Testing Anvil

1) The testing anvil serves to check out the proper operation of α hammer. It is made of steel alloy and weights 16kg. You should get the testing anvil.

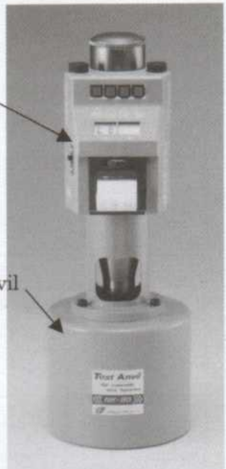
2) Instruments should be checked out every about 1500 impacts or every 6 months.

(2) How to use a Anvil

1) It must be placed on a rigid and smooth surface like concrete floor.

2) Insert the instrument like the illustration of this page. Press the instrument like concrete test, and you can read the anvil-rebound value. Read five to ten readings and calculate average value.

3) α Hammer should give readings between Ra78～82. If the Ra value differs considerably from the nominal value of 80, one will have to take this proportional difference into account when testing concrete. The following formula should be used to interpret test results.



α HAMMER
With Test Anvil

$$R = R_o \frac{80}{R_a}$$

R_o: average of concrete test data

R_a: average of anvil test data

4) This formula is practically useful up to Ra=74. At lower Ra values the instrument has to be cleaned and recalibrated at service shop or maker.

8. Maintenance and Notice of Operation

(1) Always keep the α Hammer in a clean condition and when not in use keep it in the carrying case provided.

(2) α Hammer should be checked and adjusted every 6000 impacts or every one year at a service shop.

(3) If α Hammer is damaged or its readings is not correct, it should be checked and adjusted at a service shop. Users are not able to check or adjust instruments.

(4) Don't handle your instrument toward the parts of person. Strike perpendicularly to surface to be tested or plunger slips out of the surface. Therefore you may get hurt.

(5) Please don't drop down α Hammer, don't give a shook or vibration to α Hammer.

(6) α Hammer should not be overhauled by user.

(7) On occasion of measuring you must observe followings.
Firmly hold the instrument in a position that allows the plunger to strike perpendicularly to the surface tested. Gradually increase the pressure on the plunger until the hammer impacts.

END

CUBE COMPRESSIVE STRENGTH TABLE

AGE OF CONCRETE : 14 TO 56 DAYS

R	Kgf／cm^2					R	N／mm^2					R	psi				
	-90°	-45°	0°	+45°	+90°		-90°	-45°	0°	+45°	+90°		-90°	-45°	0°	+45°	+90°
20	147	135	—	—	—	20	14.4	13.2	—	—	—	20	2,091	1,920	—	—	—
21	159	147	—	—	—	21	15.6	14.4	—	—	—	21	2,261	2,091	—	—	—
22	171	159	129	—	—	22	16.8	15.6	12.7	—	—	22	2,432	2,261	1,835	—	—
23	188	171	141	—	—	23	18.4	16.8	13.8	—	—	23	2,674	2,432	2,005	—	—
24	200	188	153	—	—	24	19.6	18.4	15.0	—	—	24	2,845	2,674	2,176	—	—
25	212	200	165	118	—	25	20.8	19.6	16.2	11.6	—	25	3,015	2,845	2,347	1,678	—
26	233	218	186	135	—	26	22.8	21.4	18.2	13.2	—	26	3,314	3,101	2,645	1,920	—
27	247	235	194	153	124	27	24.2	23.0	19.0	15.0	12.2	27	3,513	3,342	2,759	2,176	1,764
28	259	247	212	165	141	28	25.4	24.2	20.8	16.2	13.8	28	3,684	3,513	3,015	2,347	2,005
29	280	259	224	176	162	29	27.5	25.4	22.0	17.3	15.9	29	3,982	3,684	3,186	2,503	2,304
30	294	280	247	200	171	30	28.8	27.5	24.2	19.6	16.8	30	4,181	3,982	3,513	2,845	2,432
31	306	294	259	212	188	31	30.0	28.8	25.4	20.8	18.4	31	4,352	4,181	3,684	3,015	2,674
32	329	312	280	224	200	32	32.3	30.6	27.5	22.0	19.6	32	4,679	4,437	3,982	3,186	2,845
33	341	329	294	247	224	33	33.4	32.3	28.8	24.2	22.0	33	4,850	4,679	4,181	3,513	3,186
34	365	341	306	259	235	34	35.8	33.4	30.0	25.4	23.0	34	5,191	4,850	4,352	3,684	3,342
35	376	365	329	280	256	35	36.9	35.8	32.3	27.5	25.1	35	5,348	5,191	4,679	3,982	3,641
36	400	376	341	294	271	36	39.2	36.9	33.4	28.8	26.6	36	5,689	5,348	4,850	4,181	3,854
37	412	400	365	312	288	37	40.4	39.2	35.8	30.6	28.2	37	5,860	5,689	5,191	4,437	4,096
38	435	412	376	329	306	38	42.7	40.4	36.9	32.3	30.0	38	6,187	5,860	5,348	4,679	4,352
39	447	435	400	353	329	39	43.8	42.7	39.2	34.6	32.3	39	6,358	6,187	5,689	5,021	4,679
40	471	447	412	365	347	40	46.2	43.8	40.4	35.8	34.0	40	6,699	6,358	5,860	5,191	4,935
41	482	471	435	388	365	41	47.3	46.2	42.7	38.0	35.8	41	6,855	6,699	6,187	5,518	5,191
42	500	488	447	406	382	42	49.0	47.9	43.8	39.8	37.5	42	7,111	6,941	6,358	5,774	5,433
43	518	506	471	424	400	43	50.8	49.6	46.2	41.6	39.2	43	7,367	7,197	6,699	6,030	5,689
44	541	529	494	447	424	44	53.1	51.9	48.4	43.8	41.6	44	7,694	7,524	7,026	6,358	6,030
45	553	541	506	465	441	45	54.2	53.1	49.6	45.6	43.2	45	7,865	7,694	7,197	6,614	6,272
46	576	565	529	482	459	46	56.5	55.4	51.9	47.3	45.0	46	8,192	8,036	7,524	6,855	6,528
47	588	582	547	506	482	47	57.7	57.1	53.6	49.6	47.3	47	8,363	8,278	7,780	7,197	6,855
48	612	600	565	524	506	48	60.0	58.8	55.4	51.4	49.6	48	8,704	8,534	8,036	7,453	7,197
49	635	618	588	541	524	49	62.3	60.6	57.7	53.1	51.4	49	9,031	8,790	8,363	7,694	7,453
50	647	635	606	565	541	50	63.4	62.3	59.4	55.4	53.1	50	9,202	9,031	8,619	8,036	7,694
51	671	659	624	588	565	51	65.8	64.6	61.2	57.7	55.4	51	9,543	9,373	8,875	8,363	8,036
52	682	671	647	606	588	52	66.9	65.8	63.4	59.4	57.7	52	9,700	9,543	9,202	8,619	8,363
53	706	694	665	624	612	53	69.2	68.1	65.2	61.2	60.0	53	10,041	9,871	9,458	8,875	8,704
54	⇧706	⇧706	682	647	624	54	⇧69.2	⇧69.2	66.9	63.4	61.2	54	⇧10,041	⇧10,041	9,700	9,202	8,875
55	⇧706	⇧706	706	671	647	55	⇧69.2	⇧69.2	69.2	65.8	63.4	55	⇧10,041	⇧10,041	10,041	9,543	9,202

※"⇧" MEANS "OVER"

Ultrasonic non-destructive measuring instrument of concrete

Et-le-Soviet double-click

INSTRUCTION MANUAL

- speed of sound measurement

· Crack depth measurement

Thickness measurement

• Internal defect detection

Hermes Toyoko Co., Ltd.

Dong-Hermes Co., Ltd.

2009.01

security

This device, against our defects, one year warranty will apply from the date of delivery. During the warranty period, if the notification to the effect of the defect has been made to the Corporation Toyoko Hermes or Dong-Hermes Co., Ltd., Co., Ltd., Toyoko Hermes or Dong-Hermes Co., Ltd., is the repair of our responsibility, and the exchange.

However, operation, indicate the damage caused to the user has not kept related to the maintenance, defect, malfunction, operating failure are not eligible. In addition, and if the user has modified the product, abuse by users, erroneous operation, in the case of carelessness, power outages, power surges, accidents, acts of a third party, other unexpected events of that, and the subject of this warranty do not.

Warranty period

1 year

Contact

Co., Ltd. Toyoko Hermes

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This product specifications may be changed without prior notice for the improvement and improvement. Please note.

Note on the treats that Ri taken

⚠ Caution, warning and danger	❗ Instruction	⊘ Ban

⚠ Power supply, the supplied AC adapter, an external power supply, please do not use other than batteries (AA × 8 pieces). Electric shock, fire, and cause of failure.

❗ Power supply in the case of continuously over a long period of time will you use, please use the AC adapter or an external power supply, the supplied. When you wish to use batteries, please have a spare battery.

❗ If you are replacing the battery, replace with new batteries of the same type with eight. The use of mix different types or old and new, will be the cause of the failure.

❗ When not in use, to prevent leakage, please remove the batteries from the El Sonic meter.

❗ Avoid using or storing the high temperature and low temperature, please use within the range of allowable operating temperature.

❗ Use in high humidity is avoided, please use within the range of allowable relative humidity.

⊘ At the time of storage and use, please do not put a heavy object on top of the body.

⊘ When carrying, please be careful so as not to give a shock or strong vibration.

⊘ Please be careful not to pull on the AC adapter and sensor cable to impossible.

⚡ High voltage Note

- or it contains a liquid such as water is inside the body, or attached to the connector and cable

It is dangerous to be used in the state.

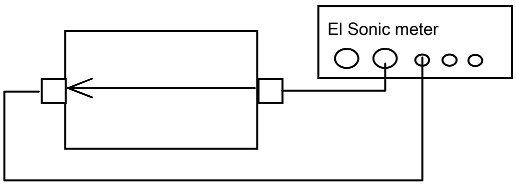
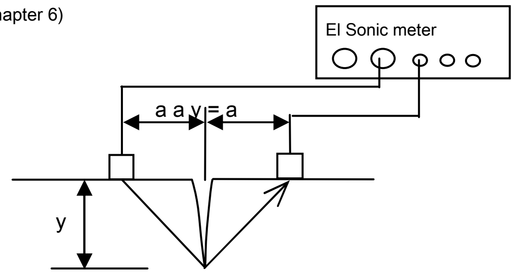
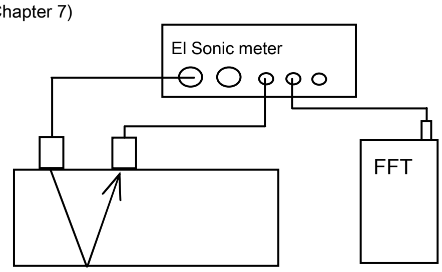
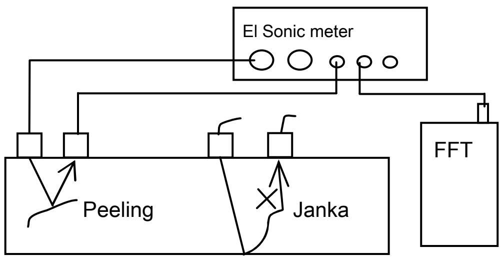
table of contents

NOTES

Chapter 1 Overview

1-1 El Sonic function of

El Sonic is ultrasonic non-destructive measuring instrument of concrete. You can make the following measurement.

Connected to the measurement method	Overview
Large ultrasonic power measurement of sound velocity by (P.13 Chapter 5) 	- You can measure the speed of sound from the ultrasonic wave propagation time. Of and structures used in health evaluation. · Uses the strength estimation of concrete. - cracks will use the speed of sound correction of the depth and thickness measurements. Concrete other than the refractory Munagawara and ceramics, it can also be used to quality assessment such as graphite.
Measurement of crack depth (see P.17 Chapter 6) 	- cracking depth can be easily measured. - cracks to the shadow of the portion of using the principle of secondary diffraction wave of the ultrasonic waves advance, will determine the depth of for cracks.
Of thickness measurement (see P.27 Chapter 7) 	• Use an FFT analyzer, by obtaining the arrival time of the ultrasonic wave of the reflected wave, you can thickness measurement. · Example) tunnel lining thickness, cover thickness rebar It is, building the wall construction thickness
Detection of internal defects (see P.40 Chapter 8) 	· By a technique transmission speed of sound measurement and thickness measurement can detect the internal defects of the structure. • Example) cavity, peeling, Janka, etc.

Features of the 1-2 El Sonic

(1) regardless of the speed of sound in concrete, also can be measured also crack depth if there is rebar.

Our unique lamp method (right angle diffraction wave method).

For more information, please refer to the P.17 "Chapter 6 crack depth measurement".

(2) output to print a printer.

You can print a digital display measured values.

For details, please see "Connecting 9-1 printing printer of the Chapter 9 peripheral equipment" P.42.

(3) You can observe waveforms on an oscilloscope.

Submit trigger output (TRIG), there is the amplifier output (OUT) connector of the received signal, you can waveform observed in the oscilloscope.

※ transmit trigger output, speed of sound measurements, and crack depth during the measurement only. For details, please see "Connecting 9-4 oscilloscope with Chapter 9 peripheral equipment" P.51.

(4) data output to an external personal computer (hereinafter PC).

In RS-232C communication, it can be measured mode switching from the reading and PC digital display value to the PC (measured value).

In addition to using the supplied sample program (Excel macro), the digital display value, can be output to Excel.

For more information, refer to P.53 "Connecting to Chapter 9 peripheral devices 9-6 PC (RS-232C)".

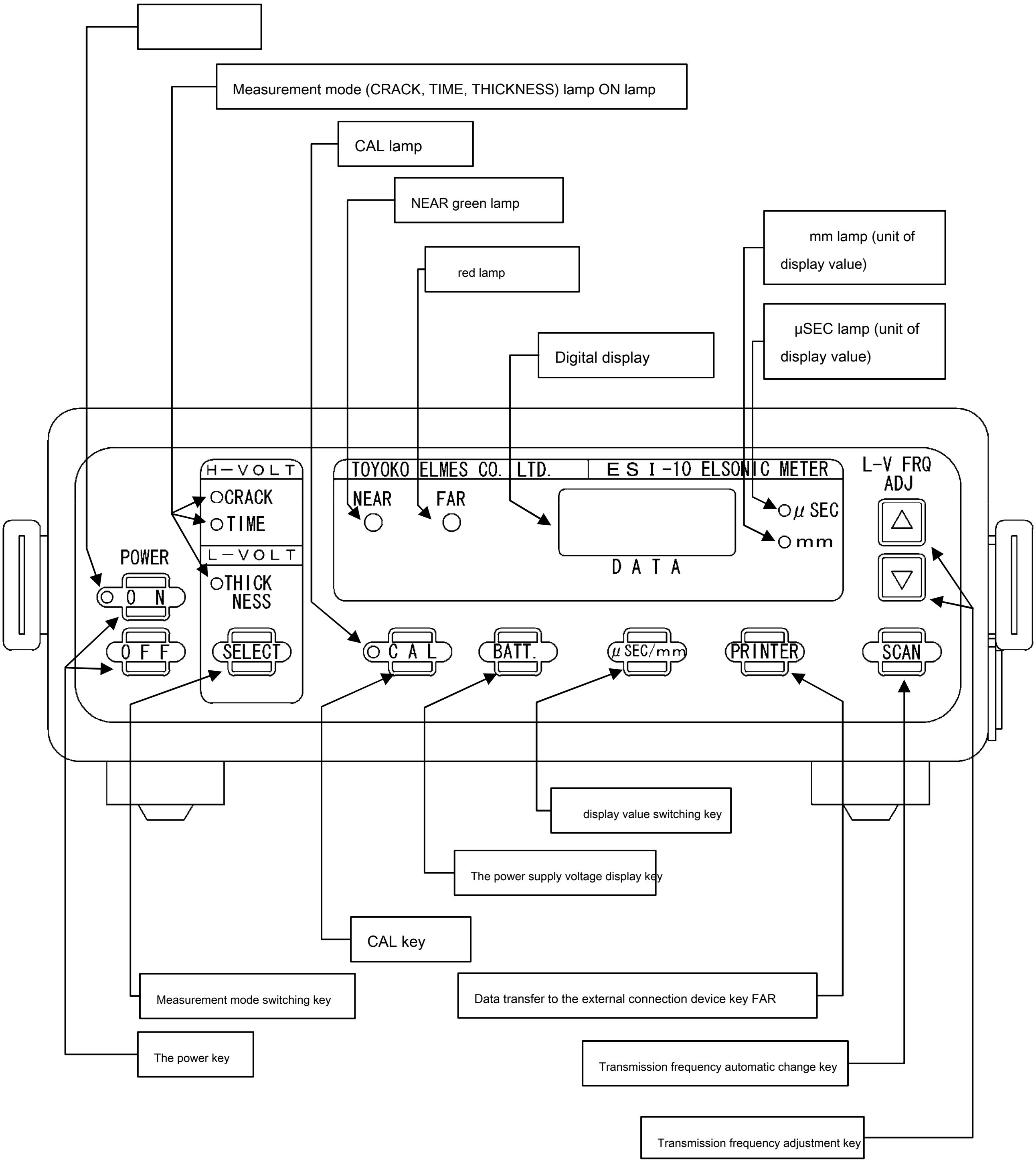
(5) You can check the remaining battery power.

You can monitor the power supply voltage by a digital value (V).

For more information, please refer to P.3 Chapter 2, "Names and Functions 2-1 front panel components".

Names and Functions of Chapter 1, each part

2-1 front panel



Key

ON / OFF Key: This is the power key.

ON the power, and OFF. When the power ON, ON lamp lights.

SELECT Key: This measurement mode switching key.

From the unselected state, time to press [CRACK (crack depth) → TIME (between the time of propagation) → THICKNESS (thickness) → not selected] will change and. It displays the measurement mode in the lamp lighting.

CRACK, when TIME the lamp is on, it sends a high-voltage pulse from the H-VOLT connector.

THICKNESS lamp is lit, it sends a low pressure continuous wave from the L-VOLT connector.

CAL Key : The CAL (CAL) key.

CRACK lamp is lit, after performing zero reset CAL value within calculation and enters a digital method mode.

TIME lamp is lit, you can make zero reset of the CAL value in the internal calculations. In either case, it will be canceled by pressing again. CAL to the effective time, CAL lamp lights. ※ For details, please refer to P.15 NOTES "CAL key".

BATT. Key : Power supply voltage display key.

While pressing, the power supply voltage will be displayed on the digital display. CRACK, can be operated at the time and measurement mode has not been selected TIME lamp lighting.

μSEC / mm Key: The display value switching key.

Each time the button is pressed to toggle the displayed value of the digital display time, or in any one of (time or obtained by calculating internal etc. sound velocity) distance. μSEC lamp, which means the unit of the display value the state at that time (time), expressed in the lighting of the lamp mm (distance).

CRACK, can be operated at the time of TIME and THICKNESS lamp lighting.

PRINTER Key: The data transfer key to the external connection equipment.

And then output the display value of the digital display to print a printer or a PC (RS-232C communication).

▲ , ▼ Key : The transmission frequency adjustment key.

Thickness during the measurement (low pressure continuous wave: L-VOLT The transmission frequency of) ▲ Up in, ▼ Lowering it in . Press and hold, changing digit will increase digit. ※ For more information P.32 NOTES "transmission frequency adjustment (▲ , ▼ Please refer to the) key. " It can be operated at the time of THICKNESS lamp lighting.

SCAN Key : The transmission frequency automatic change key.

Thickness during the measurement (low pressure continuous wave: L-VOLT) the transmission frequency 1 (kHz) from 4 (kHz) or in the, change automatically (digital display on the 2000 → 500mm) and scans it to. Pause the scan and press again, to resume the scan from further press the pause value.

If you want to scan from the beginning, re-select the measurement mode. It can be operated at the time of THICKNESS lamp lighting.

lamp

ON lamp : Indicates that the power is turned on.

CRACK lamp: Indicates that this is a crack depth measurement mode. TIME lamp

: Indicates that this is a propagation time measurement mode for the speed of sound measurement.

Even crack depth measurement, a short distance detour wave method is this mode.

THICKNESS lamp: Indicates that this is a measurement mode of thickness. CAL lamp

: CRACK lamp is lit, the zero resetting of the CAL value within calculation and digital

Law mode will not represent that it is a valid state.

TIME lamp is lit, it indicates that it is a zero reset enabled state of the CAL value in the internal calculations.

※ For details, please refer to P.15 NOTES "CAL key".

μSEC lamp: display value of the digital indicator in time, indicates that the unit is "μs".

CRACK, is effective at the time of TIME and THICKNESS lamp lighting.

mm lamp : Display value of the digital display is at a distance, it indicates that the unit is "mm".

CRACK, is effective at the time of TIME and THICKNESS lamp lighting.

It indicates that it is a (minus) - polarity of the received wave the first wave is: NEAR green lamp.

CRACK, and is valid in TIME lamp is lit.

FAR red lamp: Indicates that the polarity of the received wave the first wave is + (plus).

CRACK, and is valid in TIME lamp is lit.

display

Digital display: time, distance, and the value of the power supply voltage to a digital display.

When displaying time and distance, each measurement mode, CAL, .mu.sec, the lighting state of mm lamps differ in internal arithmetic expression El Sonic meters have different meanings indicated value.

The meaning of each lamp lighting state another display values are summarized in the table below.

CRACK lamp lighting

CAL lamp	μSEC lamp (time)	mm lamp (distance)
Extinction	Propagation time + CAL value	-
Lighting	-	FAR lamp lights up when the propagation time × speed of sound × 1/2 × 1 / √2

TIME lamp lighting

CAL lamp	μSEC lamp (time)	mm lamp (distance)
Extinction	Propagation time + CAL value	(Propagation time + CAL value) × speed of sound × 1/2
Lighting	Propagation time	Propagation time × speed of sound × 1/2

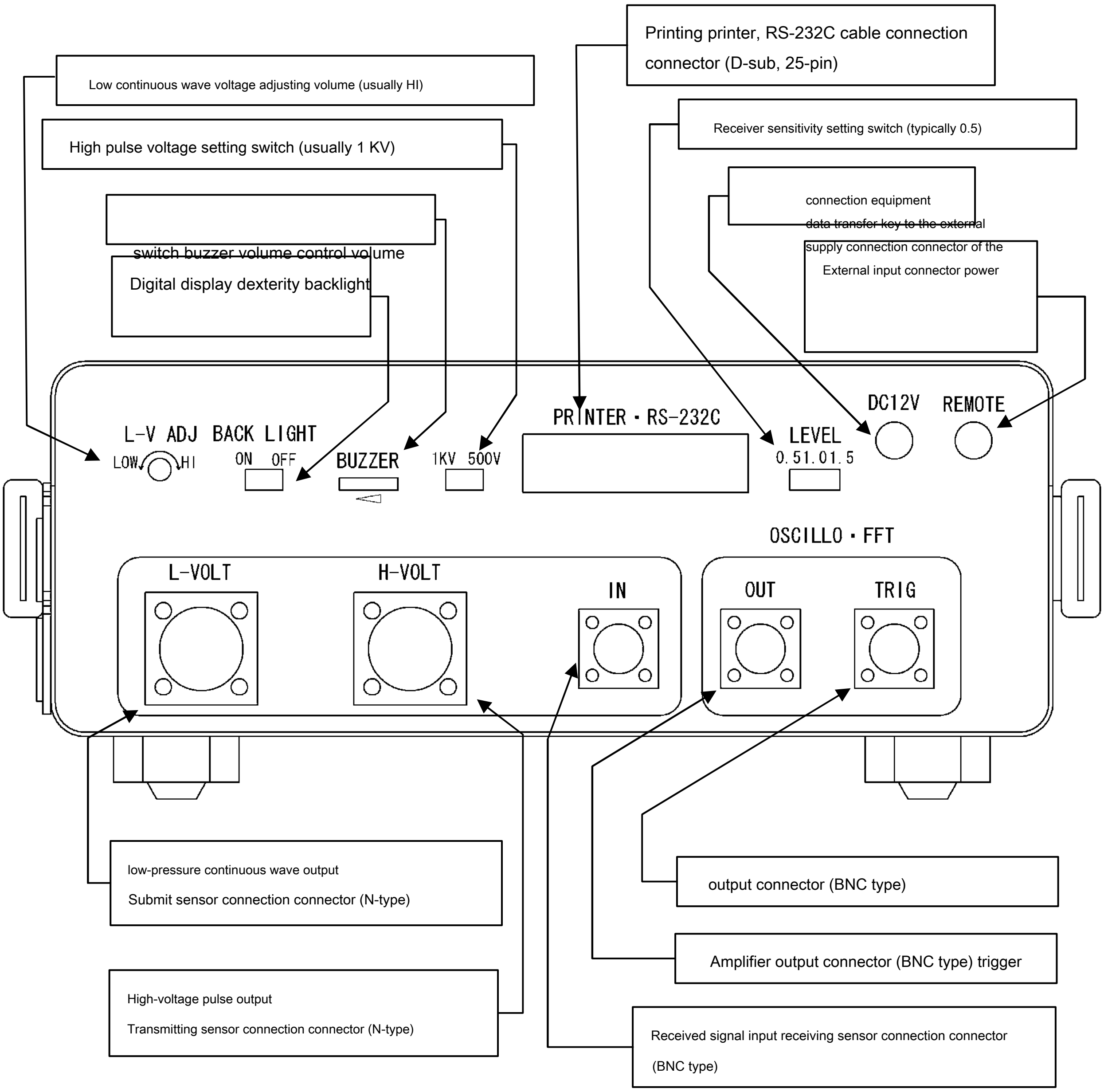
THICKNESS lamp lighting

μSEC lamp (time)	mm lamp (distance)
Period of the transmitted wave (= 1 / transmission frequency)	1 / transmission frequency × sound velocity × 1/2

※ in the internal operation of the El Sonic meter, (concrete) speed of sound is calculated in the 4000m / s. ※ or if the result of the internal operation is a negative number, NEAR green lamp is lit digital method, a display device

It is displayed as "9999".

2-2 rear panel



connector

DC12V : Power supply connection connector.

AC adapter, or connect the power cable for El Sonic the external power supply, enter the DC12V. (PRC05 connector)

REMOTE : This is an external input connector of the data transfer key to the external connection equipment.

Connect the external connection switch, such as a foot switch (sold separately). (PRC05 connector)

L-VOLT : It is to send sensor connection connector of the low-pressure continuous-wave output.

When the thickness measurement, and connect the transmission sensor. (N-type connector)

H-VOLT : It is to send sensor connection connector of the high-voltage pulse output.

Speed of sound at the time (propagation time) measurement and crack depth measurement, connect the transmission sensor. (N-type connector)

Note) Please do not connect the thickness-measuring sensor.

IN : The reception sensor connection connector of the received signal input.

Connect all of the receiving sensor. (BNC type connector)

OUT : The amplifier output connector.

Amplifying the received signal in the amplifier circuit to output. (BNC type connector) oscilloscope, and connect the FFT analyzer.

TRIG : It is the trigger output connector.

Dividing the output from the H-VOLT connector minute, and output. It is for the trigger at the time of the oscilloscope observation. (BNC type connector)

PRINTER · RS-232C: print printer, is the RS-232C cable connection connector. (D-sub25 pin)

Change-over switch

LEVEL : The reception sensitivity setting switch.

Switch the received signal sensitivity (3 levels from more sensitivity is good 0.5 / 1.0 / 1.5). (Normal: 0.5)

1KV 500V : A high-voltage pulse voltage setting switch.

Switch the voltage of the high-voltage pulse output from the H-VOLT connector. Select either 500V or 1KV. (Normal: 1KV)

BACK LIGHT : The digital display dexterity backlight switch.

It can make ON / OFF of the backlight.

volume

L-VOLT ADJ : This is a low-pressure continuous-wave voltage regulation volume.

Is output from the L-VOLT connector to adjust the voltage of the low-pressure continuous-wave. (Normal: HI side maximum)

BUZZER : The buzzer volume control volume.

Please adjust to suit the situation.

Chapter 3 Preparation

3-1 power

Please properly used by the power supply environment.

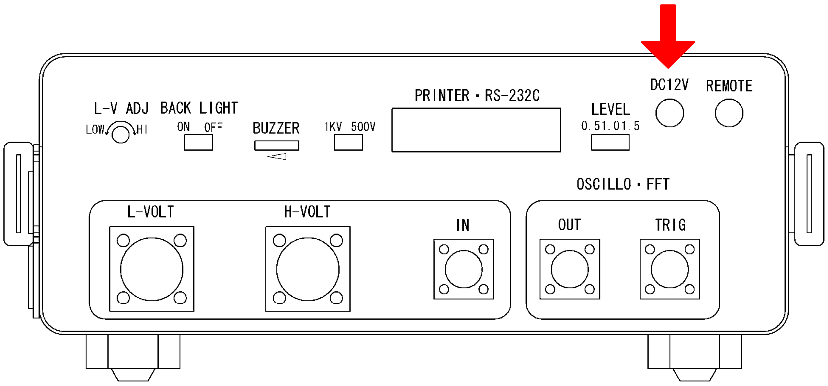
• If you AC100V there is, use the AC adapter.

· AC100V speed of sound measurement in the absence of, at the time of the measurement of large power consumption, such as crack depth measurement, it is recommended the use of an external power supply (sold separately).

· AC100V, if there is no external power supply, can be measured in the battery. In this case, please prepare a spare battery.

(1) AC adapter

On the rear panel of the DC12V connector, and connect the AC adapter accessories.



(2) batteries

① Remove while pushing the claws of: both sides as shown in the right photo the battery case (two of each place on the top and bottom) on the right side.

② battery each four AA alkaline batteries in case (a total of eight), put careful not to mistake the polarity.

Polarity is Yes and marking on the case bottom.

Once you put the battery, give it taken as the basis of the battery case.

note) BATT. Monitors the voltage value in the key, if equal to or less than 10.8V, the same kind of new battery with eight Replace to. The use of mix different types or old and new, will be the cause of the failure. Also when not in use, to prevent leakage, please remove the battery.

(3) an external power supply (recommended product)

Manufacturer: large self-Industrial Co.,

Ltd. Model: SG-1000

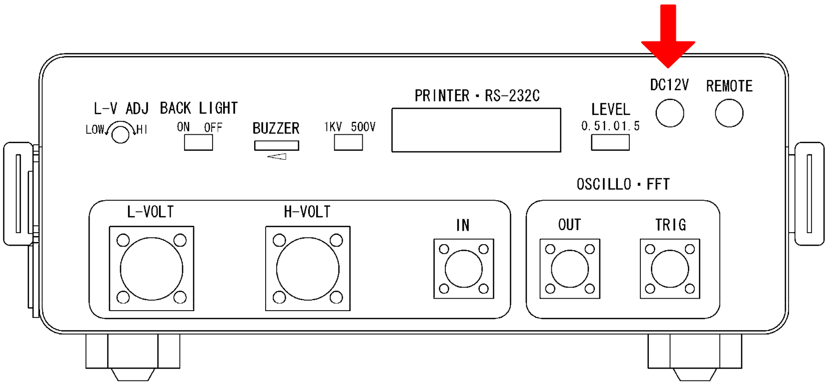
Accessories: El Sonic for power one cable, one car (12V) code for charging

Household (AC100V50 / 60Hz) 1 one charging adapter, portable shoulder bag one specification:

Item	Contents
Built-in battery DC12,7.0Ah, high-performance sealed lead-acid battery output voltage	
	DC12V
fuse	10A (body)
Body dimensions	Width 160 × height 160 × thickness 70mm
mass	About 3.2kg
socket	Cigar lighter type socket (within 84W) 2 places

Connection: on the rear panel of the DC12V connector, power cable (outside for an external power supply El Sonic

Connect with the supplied) to the department the power supply.



note) BATT. Monitors the voltage value in the key, if equal to or less than 10.8V, electricity for El Sonic from an external power supply

Remove the source cable, please charging car charging cord or a home charging adapter,. Taking the DC output while charging, it will be the cause of the failure.

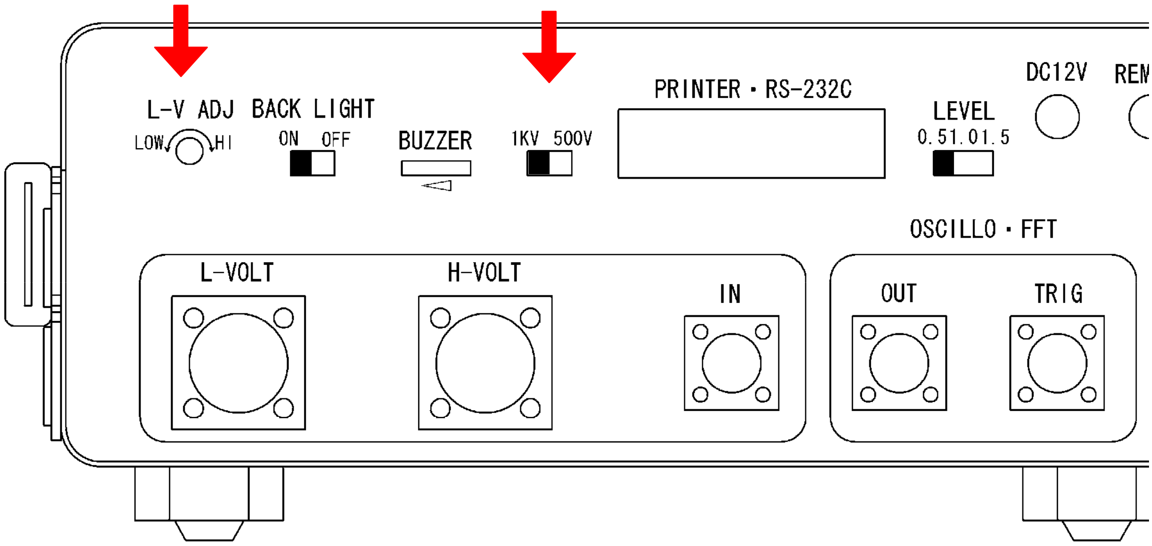
※ other specifications, details about handling please refer to the instruction manual of SG-1000.

3-2 adjustment of the transmission voltage

The transmission voltage is set at the factory, but please adjust as necessary.

item \ Transmission type	H-VOLT high-voltage pulse	L-VOLT low pressure continuous wave
Measurement of object	Speed of sound measurement crack depth measurement	Thickness measurement
Location to adjust	1KV 500V switch on the rear panel of the center	The rear panel of the upper left corner of the LV ADJ volume
type	Slide switch	Trimmer (adjusted with a small flat-blade screwdriver)
Adjustment range (usually)	500V / 1KV (1KV)	0 ~ 12V (12V: HI side maximum)
Description	- cracks when a long period of time for continuous use a small Sensor is, Shi desirable person who was lowered to 500V Idesu.	- When using a crack-sound velocity sensor over to transmission sensor, distorted reception waveform received voltage of the direct wave is too high, it becomes impossible Fourier analysis in FFT, and the Torimabori volume in an intermediate position.

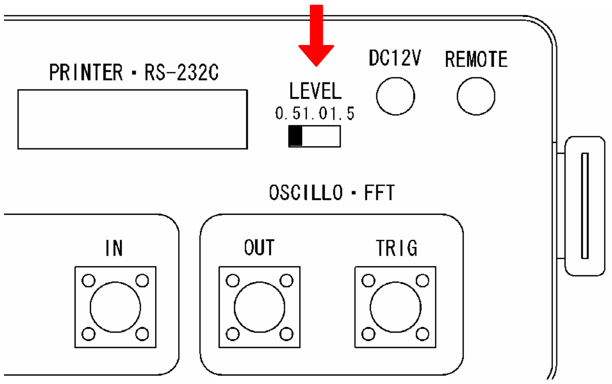
L-VOLT (low pressure continuous wave) H-VOLT (high-voltage pulse)



3-3 Setting the reception sensitivity

Measurement speed-of-sound	measurement of the subject, crack depth measurement (thickness measurement does
not matter) place to adjust	The rear panel upper right corner of the LEVEL switch
type	Slide switch
Adjustment range (usually)	3 stages from person good sensitivity 0.5 / 1.0 / 1.5 (0.5)
Description	• In heavy machinery, etc., the noise, the vibration is in the environment, can not be an accurate measurement, noise, or stop the vibration, but must be measured by shifting the time, if that is not possible, please drop the sensitivity. - Dropping the sensitivity, speed of sound is a little slow at the speed of sound measurement, in the measure crack depth, the maximum depth is reduced that can be measured.

Reception sensitivity change-over switch



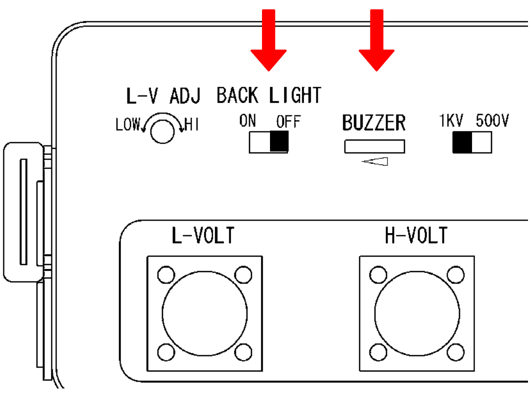
3-4 backlight ON / OFF

Lights and sliding the switch of the rear panel upper left corner of the BACK LIGHT to ON (left) side. To turn off Slide the OFF (right) side.

3-5 adjust the buzzer volume

To increase the volume going to turn the volume on the right side of the rear panel upper left corner of the BUZZER. To decrease the volume, turn to the left.

Backlight ON / OFF buzzer volume adjustment



Chapter 4 Notes on the measurement

In order to perform accurate measurement, via the coupling medium, it is important to firmly close contact with the measurement surface of the sensor and the concrete.

Please perform the measurement in mind the following points for that.

4-1 pre-processing of the measurement surface

In order to improve the transmission of ultrasonic waves, it eliminates the unevenness of the concrete surface to be measured. - Wheels in and polishing in the following flatness of 0.5 mm. Brush with drops and sand.

4-2 application of the contact medium

For better transmission of ultrasound, Apply couplant measuring surface contacting the sensor. - contact medium, please use some of the viscosity, such as grease. - contact medium, apply to sufficiently penetrate the concrete surface. How to paint the contact medium to the sensor (purpose eliminate the bubbles) is not recommended. · Sand like inclusions in the couplant Please excluded.

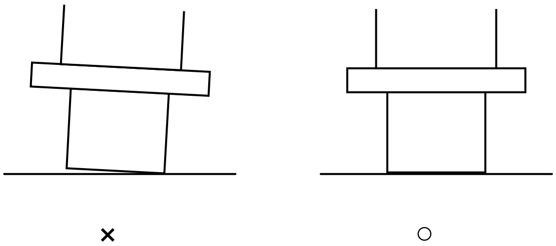
- Crack depth during the measurement, please be careful not to put the contact medium in the cracks.

4-3 how to hold the sensor, How to apply

To stabilize the transmission of ultrasound, in order to stabilize the measured values, how to hold the sensor, such as the following to the How to apply to the measurement surface.

And right have the flange portion of the sensor bottom like a photograph by placing a finger, measuring surface (or surrounding structure, etc.) in the hands of the sides and wrist, and the like put like elbows, sensors to measure surface so as not to move Te, and it firmly teeth fixed.

Sensor vibration surface is pressed to be parallel to the contact with respect to the measurement surface.



• During measurement, pressing a sensor with a force constant (about 1 to 3kg) to the measurement surface. • When moving the sensor, please do not slide while pressed. (Sensor vibrating surface is shaved)

Chapter 5 speed of sound measurement

About 5-1 speed of sound measurement

(1) speed of sound calculation of concrete

This was calculated from the following equation.

Speed of sound = propagation distance ÷ propagation time

(Speed of sound concrete is often 4000m / s ± 10%) (distance in the scale or the like, and measure the propagation time in El Sonic)

(2) measurement principle of the propagation time

① El Sonic meter, generates a high voltage pulse of 1KV or 500V (selected in the rear panel), I will send to the transmitting sensor.

② by the piezoelectric effect of the piezoelectric element in the transmission sensor, ultrasonic waves will occur. ③ ultrasound is transmitted to the opposite side of the reception sensor propagates through the concrete. ④ receiving sensor is a voltage generated by the piezoelectric effect, it sends to El Sonic meter. In ⑤ El Sonic meter, from the sending to the receiving signal is inputted, the resolution of 0.1μs

In the measurement, and then displayed on the digital display.

(3) Other

You may want to practice while watching the oscilloscope waveform before going to the site. FAR red, also you will find a stable condition in the fluctuation of the value of the blinking and digital display of the NEAR green lamp.

5-2 transmission speed of sound measurement

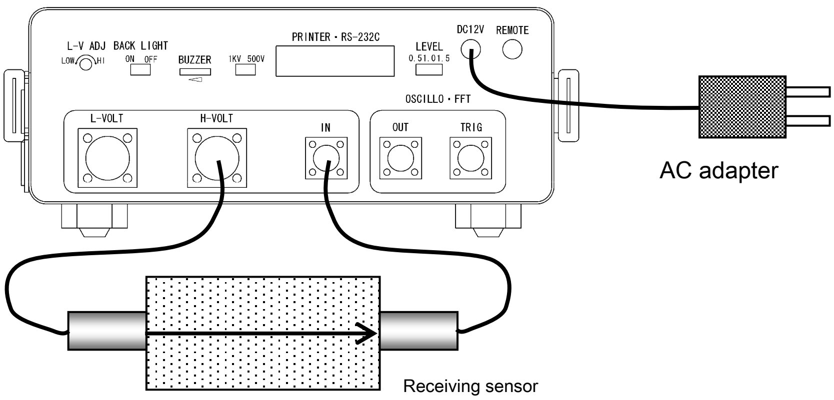
(1) Overview

Sound velocity correction of the measurement data (digital method, a short distance detour wave method, thickness measurement) and, to use the evaluation of the presence and soundness of the internal defects.

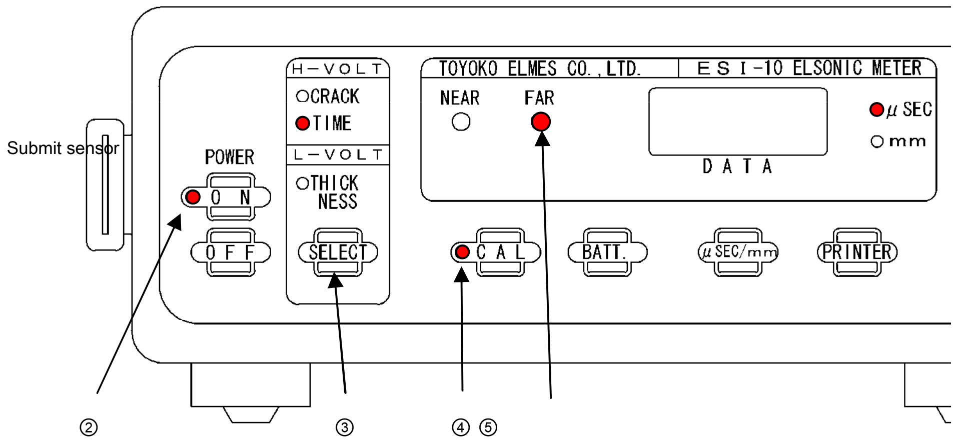
<table>
<tr><th>Item</th><th colspan="3">Contents</th></tr>
<tr><td>Use sensors and measurement range (standard)</td><td colspan="3">(Transmission) (Reception)
It cracked a small sensor crack small sensor: 60 (mm) or less cracked, sound velocity sensor crack-sound velocity sensors: 1000 (mm) or less cracked powerful sensor crack-sound velocity sensors: 3000 (mm) or less</td></tr>
<tr><td>accuracy</td><td colspan="3">Repeatability in ± 0.3μs ※ same concrete surface with a length of 250 mm</td></tr>
<tr><td>Measurement mode</td><td colspan="3">TIME</td></tr>
<tr><td rowspan="3">Meaning of the digital display value</td><td></td><td>μSEC lamp lighting</td><td>mm lamp lighting</td></tr>
<tr><td>CAL lamp off</td><td>Propagation time + CAL value</td><td rowspan="2">Display value is intended for short-distance detour wave method, it is not required for the speed of sound measurement</td></tr>
<tr><td>CAL lamp lighting</td><td>Propagation time</td></tr>
<tr><td>Configuration</td><td colspan="3">LEVEL = 0.5 HV = 1KV</td></tr>
</table>

(2) the measurement procedure

① sensor as shown in the figure below, and connect the AC adapter to El Sonic meter.



② ON Press the key to put the power. ON lamp lights. ③ SELECT Press the key twice, to light the lamp TIME.



determine the speed of sound, repeated measured by the measurement point is a little movement, Masu asked Me the average value. We can make ④CAL. (For details, see note to the column "CAL key" on the next page) lightly against face-to-face the sensor with

each other, to confirm the CAL value, CAL Press the key. · CAL lamp is lit, make sure that the value of the digital display has been reset to zero. ⑤ measurement of the propagation time

- polishing the measurement surface, and give the contact medium. P.12 in such a manner that the center axis of the Chapter 4, "Notes on the measurement" reference, transmission and reception sensor is the same, you rely on the sensor plane of vibration in the concrete surface.

· FAR red lamp lights, digital display value (μSEC) will read the value at the time of stability. ※ When you want to more accurately

CAL key

【Overview】

Measurement mode CRACK, or when the TIME, by facing the sensor each other (across the contact catalyst quality) a plane of vibration will be contacted.

Digital display value El Sonic meter at that time, the propagation time from the piezoelectric element in the sensor to the piezoelectric element, and is delayed total time of the electrical signal.

This display value CAL (CAL) value and is referred to, will vary greatly value depending on the type of sensor (for example, sending CAL value ≒ 13.0μs at the time of both and receive cracked-sound velocity sensor). In addition, there is also some of the instrumental error for each product.

Actual CAL value is given on the inspection results table attached to each sensor. • Press the CAL key is zero reset the CAL value, we call this operation and known as CAL (CAL).

【the purpose】

· Unnecessary time that is included in the digital display value (CAL value), you can reset to zero. - CAL value, if it is properly displayed, outputs from El Sonic meter pulse signal is successfully transmitting receiving sensor and is transmitted successfully to the receiving portion of the El Sonic meter, simple of what is displayed, you can specific confirmation.

[Act of measurement for each mode]

CRACK: zero-resetting the CAL value, the digital method arithmetic processing inside El Sonic meter model

It will transition to over de. Please refer to the P.24 "6-3 digital method". TIME:

Do the zero reset of the CAL value.

[CAL procedure]

Sensor with a small amount of contact medium to the plane of vibration of, straight are opposed to the sensor with each other on the floor or desk, align the vibrating surface. Note) This is easy to do it is stable to have at hand. · CAL value is the same value as the normal, Furatsuka Not To make sure that it is stable display. - without moving the sensor in this state CAL Press the key.

· CAL lamp lighting (CAL enabled) to confirm, in the digital display displays the value close to 000.0, CAL is complete (CAL unless terminated effective).

[CAL Release Procedure] - again CAL Press the key, turn off the power CAL will be canceled.

[If you do not a CAL]

- Please subtracting the CAL value from the measured value of the propagation time.

[If the CAL value is not displayed correctly]

· P.66 Please refer to "Appendix -3 Troubleshooting".

5-3 surface speed of sound measurement

(1) Overview

Speed of sound correction and if the transmission speed of sound measurement can not be performed (not rely on the sensor only in the same plane), and then use the strength estimation of concrete.

El Sonic is the only propagation time measurement, for the strength estimation method, because there are a number of ways, please speed of sound measured along each of the literature. Example) "ultrasonic testing (PWRI method) structure concrete strength measurement procedure of the newly established by the (draft)", etc.

<table>
<tr><th>Item</th><th colspan="3">Contents</th></tr>
<tr><td>Use sensor</td><td colspan="3">(Transmission) (Reception)
Crack-sound velocity sensor crack-sound velocity sensor cracks
powerful sensor crack-sound velocity sensor</td></tr>
<tr><td>Measurement mode</td><td colspan="3">TIME</td></tr>
<tr><td rowspan="3">Meaning of the digital display value</td><td></td><td>μSEC lamp lighting</td><td>mm lamp lighting</td></tr>
<tr><td colspan="2">CAL lamp off propagation time + CAL value</td><td rowspan="2">Display value is intended for short-distance detour wave method, it is not required for the speed of sound measurement</td></tr>
<tr><td>CAL lamp lighting</td><td>Propagation time</td></tr>
<tr><td>Configuration</td><td colspan="3">LEVEL = 0.5 HV = 1KV</td></tr>
</table>

(2) the measurement procedure

It is the same manner as the speed of sound measurement of P.14.

Chapter 6 crack depth measurement

6-1 for crack depth measurement

In El Sonic, and the mainly crack depth measurement in the lamp method (right angle diffraction wave method). - as an auxiliary function, digital method, it can also be measured in the short-distance detour wave method.

Contents	The main function	Auxiliary function	
	Lamp method (right angle diffraction wave method) (See P.18)	Digital method (see P.25)	Short distance detour wave method (see P.26)
Overview	Distance from crack to the reception position of the diffracted wave = crack depth Measured on a scale	It is the same as the lamp method is not measured by the scale, read the value of the digital display	Calculated from the time from when the transmission, and receiving a return wave pulling down with crack tip
The measurement principle	right angle diffraction wave	Right angle diffraction wave + propagation time of the received wave	Propagation time of the received wave
Sensor connected to the	transmission sensor: the rear panel of the H-VOLT connector (N-type) Receiving sensor: the rear panel of the IN connector (BNC type)		
Sandwiching the sensor	position cracking, both sensors Spread gradually over	Same as on the left.	Cracking the vicinity
Measurement mode	CRACK	CRACK	TIME
Speed of sound correction	unnecessary	Required	Required
Calculation	Unnecessary	Necessary at the speed of sound correction	Necessary at the speed of sound correction
CAL	Unnecessary	Required	Required
Single-position of the display value	Display value unnecessary	mm (switching is impossible)	μSEC, mm (switchable)
mm display at the time of Internal arithmetic expression -		Propagation time × 4000m / s × 1/2 × 1 / √2	Propagation time × 4000m / s × 1/2
Configuration	LEVEL = 0.5 HV = 1KV	Same as on the left.	Same as on the left.
Advantages	Lamp and buzzer at the crack depth it is possible to know the mild sand clogging or contact also effective in the measurement of narrow cracks depth was about to	Printer, the output can be to the PC	Measurable in unmeasurable of the situation of the lamp method
Shortcoming	If non-measurable corners on both sides of the cracked two or more is not measurable	When the distance between the crack and the sensor is left unequal error has	Not be excluded rebar, the effect of clogging

6-2 lamp method (right angle diffraction wave method)

(1) Overview

A typical crack depth measurement, and apply this method.

Speed of sound correction is unnecessary. The reinforcing bars in the middle cracks, clogging can be detected cracks tip further depth has position even if the contact portion.

Item	Contents
Use sensors and measurement range (standard)	(Transmission) (Reception) It cracked a small sensor crack small sensors: 5 ~ 30 (mm) cracks, the sound velocity sensor crack-sound velocity sensors: 30 ~ 500 (mm) cracks powerful sensor crack-sound velocity sensors: 400 ~ 1500 (mm)
accuracy	± 5 mm (when the depth of 5 ~ 30 mm flat face) (when the depth of 30 ~ 150mm flat surface) ± 10 mm ± 10% (when more depth 150mm flat surface)
Measurement mode	CRACK
Digital display Meaning display of the values is intended for the digital method, it is not required to ramp method	
Configuration	LEVEL = 0.5 HV = 1KV

Usually, in the ultrasonic measurement, but we have to measure using the phenomenon of straight or diffusion of the ultrasonic wave propagation time, right-angle diffraction wave method has the following features. - diffraction (radio waves or light goes around to the part of the shadow) use of the phenomenon.

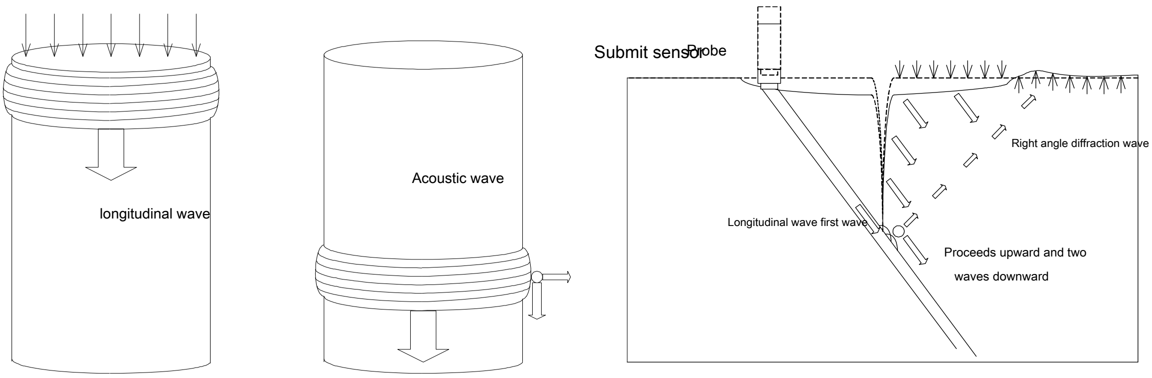
However, since concrete is elastic body, diffraction waves sound, radio waves, light and different appearance is. Direct wave of majority traveling in a straight line is not available. And interference using a long ultrasonic wavelength in order to avoid.

The following table lamp method (right angle diffraction wave method) and is applied to the comparison of the main propagation time method.

Contents	Lamp method (right angle diffraction wave method)	Propagation time method (BS method, tc-to method, etc.)
Measurements matters	Receiving the position of the diffraction wave	Time of the received wave
Calculation processing by gradually widening the measurement method from the position cracking of the		
sensor	Unnecessary	Need to calculate the calculation of each measurement method
Speed of sound	Unnecessary	Required
longitudinal wave	It must be long wavelength	Wavelength is unquestioned
wave	The first wave is necessary	Normally, the first wave
Concrete measurement	Optimum	Optimum
Anisotropic material measurement (rock, wood)	Wave advances diagonally (which can not be properly measured)	Speed of sound is different in the direction (which can not be properly measured)
Rebar, the effect of the intervention of a grain of sand, etc.	Affected but detectable cracks destination end deeper than intervening position position	Rebar, can only measurement to a depth of clogging

(2) measurement principle

Sending longitudinal elastic member rod, the points of the surface of the rod moves in the transverse and axial direction. Bar when waves of dense will bulge in the lateral direction, but this is called dynamic Poisson's ratio effect. It relies on the transmission sensor in the vicinity of the cracks, when you also sent, secondary wave in the vicinity of the crack tip has occurred. Directly to the shadow portion of the crack wave and at right angles proceeds small diffraction wave (perpendicular diffracted wave by the dynamic Poisson's ratio effect), the return wave to the surface by shear forces pulling the portion of the shadow of cracking down.

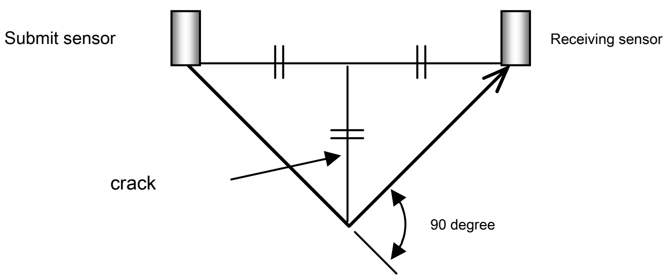


Propagation of the first wave

The point of the surface of the elastic body
Move to the horizontal and the lower

The principle diagram of the crack depth measurement

Now, if we measure the received wave while away the-receiving sensor sent at regular intervals in the form of both sides of the cracks, the first wave is there is a position where the upward (right angle diffraction waves) from the downward (return wave). Positional relationship when this becomes a line connecting the two sensors bottom, right angle isosceles triangle whose vertices tip of cracks will be distance = crack depth of crack and the sensor.



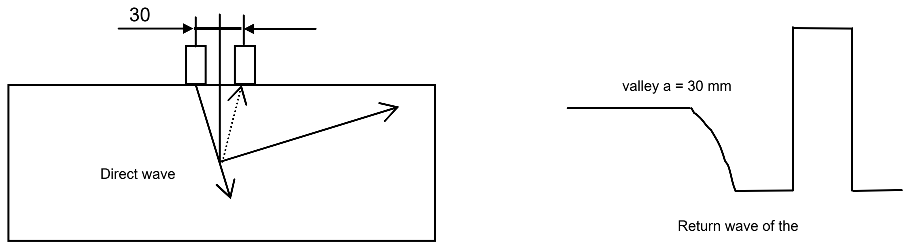
The positional relationship of both sensors and cracking

Sensor position and of the received wave relationship

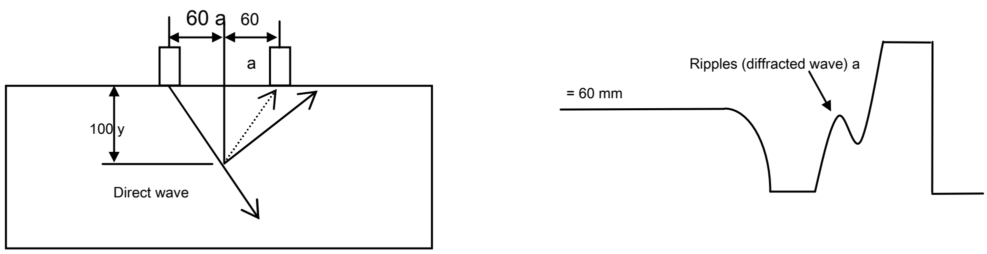
The following case of measuring the crack depth 100mm lamp method is diagram schematically showing the relationship between the sensor position and the received waveform.

The received waveform is a waveform obtained by observing the amplifier output of the received signal with an oscilloscope.

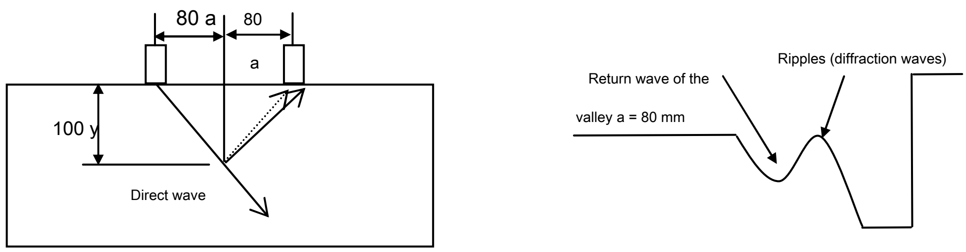
① Sending ultrasound-receiving sensor sent near Place cracks, at the tip of the crack, the shear force of the feed wave, since return wave, which lowered the shaded areas to the bottom, the first wave of the received wave It will appear in the minus direction. (Not a reflection wave from the bottom of the concrete specimen)



② is similar waveforms away a little from the cracks of the sensor. However, try to note, another small wave you will see the overlap in the positive direction.



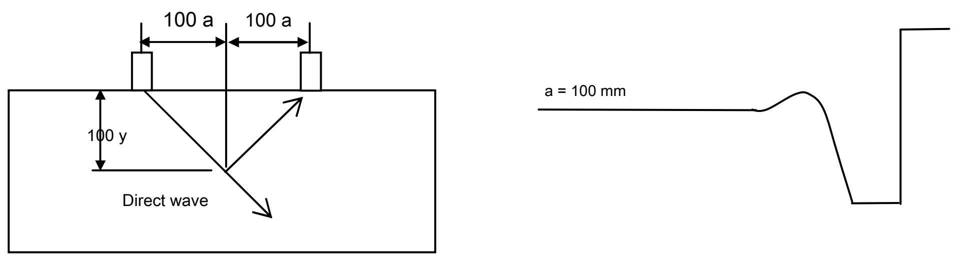
③ and further expand the two sensors, the valley of the return wave is small, the wave of plus the above-mentioned to or larger. This wave, an upward
30
wave return wave and reverse, is diffracted wave propagating in a propagating direction perpendicular wave feeding at the tip of the crack (direct wave) (towards the shadow of cracking).



④ cracked the first wave of the received wave and releases to the same distance as the depth - will change from (minus) on the + (plus). This is because caught the upward wave (right angle diffraction wave).

Positional relationship at this time will the line connecting the two sensors to an isosceles right triangle whose vertices base, the tip of the crack. Thus, by measuring the distance a from the cracks of that time to the sensor, crack depth y you will be prompted (y = a).

El Sonic, tells in FAR red lamp and buzzer captures the diffracted wave.



(3) the measurement procedure

Across the cracks, it will expand the transmission and reception sensor interval, determine the position in the lamp and buzzer, and then measuring the specific beauty crack depth.

In the same manner as the speed of sound measurement of ①P.14 connected, sensor, the AC adapter to El Sonic meter, electricity The source input Will. ② SELECT Press the key once to turn on the lamp CRACK. CAL (zero reset operation) is not required.

③ scissors cracks, pressed at regular intervals both sensors in the left and right (Figure 1), make sure NEAR green lamp lights up.

④ We will gradually expand the sensor interval.

Please be careful so that the distance until both sensors are the same from cracking. From ⑤NEAR green lamp, changes to the FAR red lamp, and marking at the buzzer rang. Also FAR red light is on further expanding the sensor interval, if it continues to sound a buzzer, it is a position where the marking position is equivalent to the depth of the cracks.

If, FAR red lamp is turned off, If you return to the NEAR green lamp, Re cracks divided by marking position is in contact (rebar, clogging, etc.).

⑥ and then measured on a scale the distance a from the sensor to the cracks in this position. ⑦a Gahibiware is the depth y .y = a (Fig. 2)

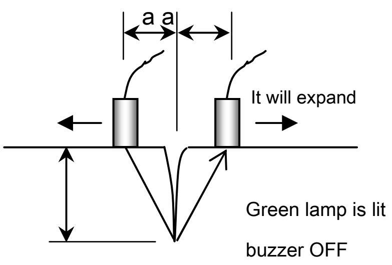


Figure 1 y> a y

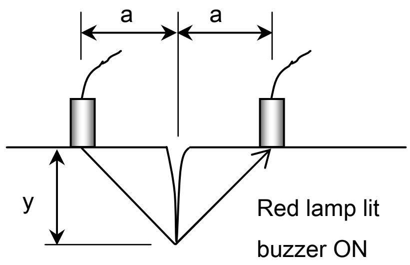
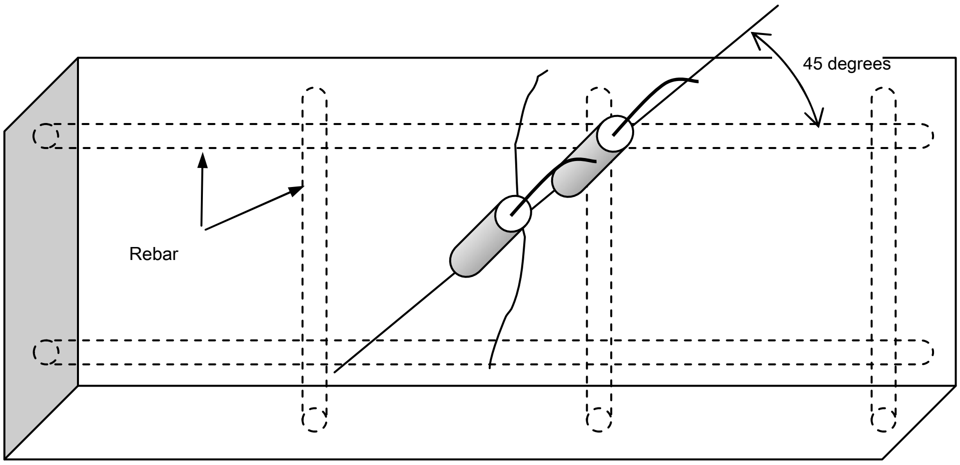


Figure 2 y ≦ a

(4) If there is a rebar

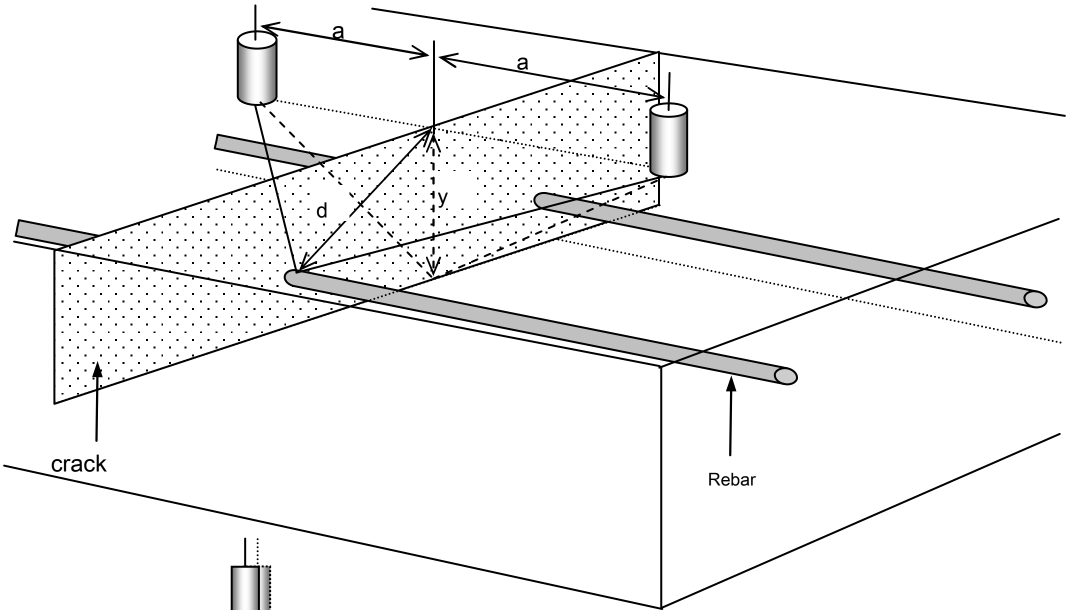
① crack depth, when deeper than the head of the rebar, or the direction that will expand the sensor on both sides of the case-cracking can not guess in advance, with respect to the axial direction of the rebar, tilt about 45 degrees.

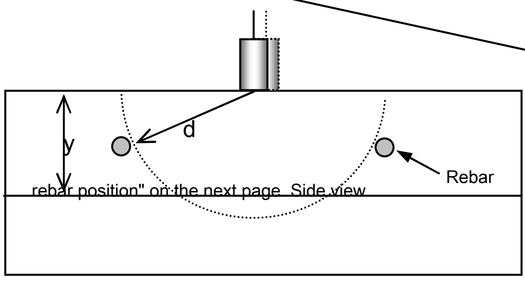
And just above the rebar would spread the sensor (as along the rebar), it will be affected by the wave that propagates through the rebar before the arrival of the right-angle diffraction waves from the crack tip. Therefore, in order to make the most mitigate the effects of vertical and horizontal stripes, and tilt 45 degrees. ※ usually measured in this way.



② If the crack depth is shallower than the head of the rebar, the distance d from the sensor as shown in the figure below until the rebar is, if distant than the distance y to the crack depth

- Even against rebar and parallel to the sensor, it can crack depth measurement.





d> y y: Crack depth

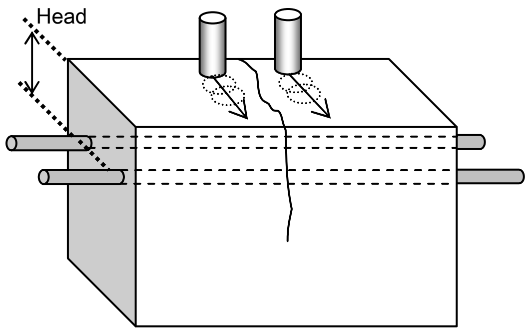
d: the distance from the sensor to the rebar

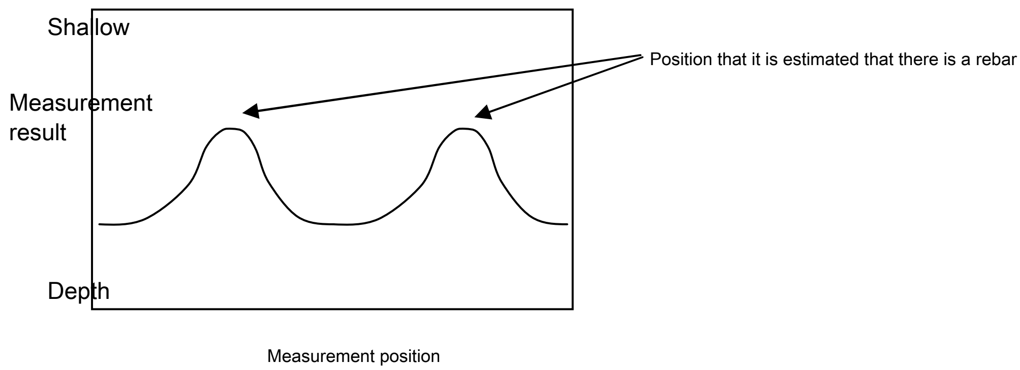
※ in the crack depth measurement method, you can estimate the approximate position of the rebar. Please refer to the column "estimated rebar position" on the next page. Side view

The estimation of the rebar position

If the head thickness of rebar is shallower than the crack depth is a crack depth measurement method, you can estimate your approximate location of the rebar.

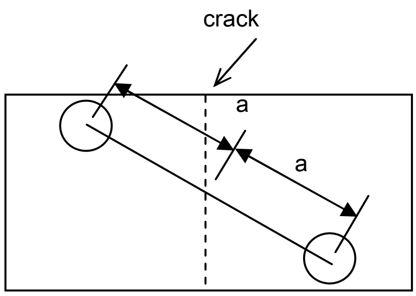
- one along the cracks, we can make crack depth measured in the number of measurement points while moving the measurement position as shown below (lamp method, a digital method, and a short distance detour wave method). · Then, just above the rebar, since most shallow value is measured, it can be estimated rebar position.





(5) If you do not spread the sensor in the form of restriction of the structure to open the sensor at an angle

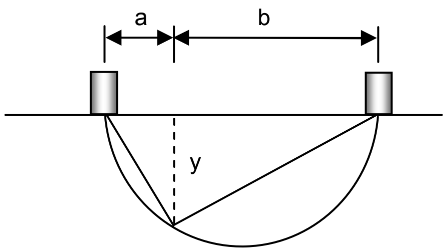
instead of cracking and the right angle, in the same way we ask for a.



(6) If you do not spread left and right sides the same sensor

When the left and right is left and right, not the same is different in a and b, crack depth is calculated by y = √ (a × b).

(However, if you crack is in the right angle to the surface)

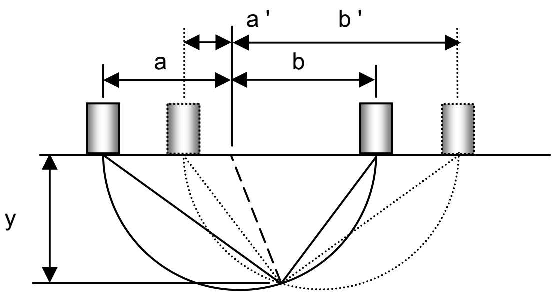


(7) In the case of a crack that went diagonally with respect to the surface

① the left and right non-target to sensor distance of the sensor and measured by changing a, and b, a then the same operation in a different distance ', b' and determined to.

②a + b and a '+ b' Draw a circle whose diameter, the intersection of the two circles is the end position of the crack (depth and angles).

③ shed transmission sensor to the closer of the tip of the crack in the left and right of the crack when the sensitivity is improved or be.



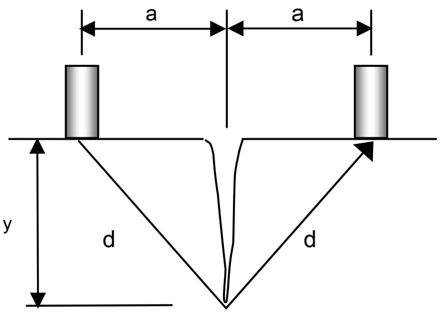
6-3 digital method

(1) Overview

Although the measurement principle is the same as the lamp method, the ultrasonic wave propagation time at right angles diffracted wave detection, in internal operations crack depth, and displays a digital value. Output to a printer or a PC is available.

Item	Contents		
Use sensors and measurement range (standard)	(Transmission) (Reception) It cracked a small sensor crack small sensors: 5 ~ 30 (mm) cracks, the sound velocity sensor crack-sound velocity sensors: 30 ~ 500 (mm) cracks powerful sensor crack-sound velocity sensors: 400 ~ 1500 (mm)		
Measurement mode	CRACK		
Meaning of the digital display value		μSEC lamp lighting	mm lamp lighting
	CAL lamp off	propagation time + CAL value	-
	CAL lamp lighting	-	FAR propagation time [calculated at 4000m / s] × speed of sound at the time of lighting × 1/2 × 1 / √2
Configuration	LEVEL = 0.5 HV = 1KV		

(2) measurement principle



When it detects a right angle diffraction wave (right), the propagation distance 2d consists of the speed of sound propagation time and the concrete and the formula ①.

Propagation distance 2d = propagation time × speed of sound Equation ①

then crack depth y is expressed by the formula ② from the relationship between the propagation distance 2d.

Crack depth y = propagation distance 2d × 1/2 × 1 / √2 ··· formula ② Thus crack depth y is the formula ③.

The crack depth y = propagation time × speed of sound × 1/2 × 1 / √2 ··· formula ③ speed of sound concrete and 4000m / s, and digital display the calculation result of the formula ③.

(3) the measurement procedure

In the same manner as the speed of sound measurement of ①P.14 connected, sensor, the AC adapter to El Sonic meter, electricity The source input Will. ② SELECT Press the key once to turn on the lamp CRACK. The ③CAL line It does not.

note) CAL CAL lamp in the key operation, and mm lamp lights.

The digital display, FAR red lamp to lit, will not be displayed measured value. ④ scissors cracks, and pressed at regular intervals both sensors on left and right. ⑤ applied from a position close to the crack, make sure NEAR green lamp.

⑥ further widened the distance between the sensor, changes from NEAR green lamp in FAR red lamp, stop at the buzzer was sounding Tsu.

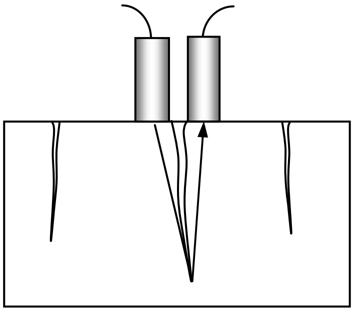
At the position of the ⑦FAR red lamp lit, cracking depth (mm) is a digital display. However, because the value at the time of the concrete sound velocity 4000m / s, and then corrected in the following manner. ※ speed of sound method of correcting a digital method

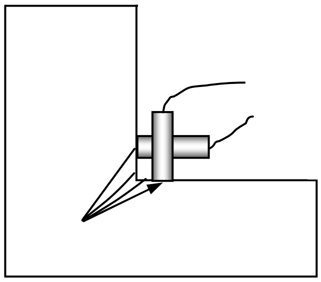
Measuring the typical cracks in structures, a lamp method using the scale, determine the ratio of the digital value, and correcting the digital value of the lamp method for true.

6-4 short distance detour wave method

(1) Overview

And when a short time has to be a large number of measurements, widen the sensor distance as shown below when the results across the crack two or more, or when the measured non-cacheable in ramp method as cracks in the corners , to apply this method.





Item	Contents		
Use Sensor and the measurement range (standard)	(Transmission) (Reception) It cracked a small sensor crack small sensors: 5 ~ 30 (mm) cracks, the sound velocity sensor crack-sound velocity sensors: 30 ~ 500 (mm) cracks powerful sensor crack-sound velocity sensors: 500 ~ 1500 (mm)		
Measurement mode	TIME		
The meaning of the digital display value		μSEC lamp lighting	mm lamp lighting
	CAL lamp off	propagation time + CAL value	(propagation time + CAL value) × speed of sound [4000m / s In calculation] × 1/2 ※ It is not required for the measurement
	CAL lamp lighting	Propagation time	[Calculated at 4000m / s] × propagation time × speed of sound 1/2
Configuration	LEVEL = 0.5 HV = 1KV		

(2) measurement principle

The tip surface and cracks (said in the lamp method, the return wave from the crack tip) longitudinal wave which reciprocates crack depth y from the propagation time and the speed of sound is expressed as:.

Crack depth y = propagation time × sound velocity × 1/2

The speed of sound of concrete and 4000m / s, and digital display the result of the operation.

(3) the measurement procedure

This measurement method is intended to read the value of the display device by applying the sensor. In the same manner as the speed of **sound measurement of ①P.14 connected, sensor, the AC adapter to El Sonic meter, electricity The source input Will. ② SELECT Press the key twice, to light the lamp TIME. We can make ③CAL. ④ μSEC / mm Press the key, to light the lamp mm.**

⑤ across the crack, in a position close by (sensor each other, to the extent not contact) can be, the transmission and reception sensor, pressed. ⑥ digital display value is the crack depth (mm).

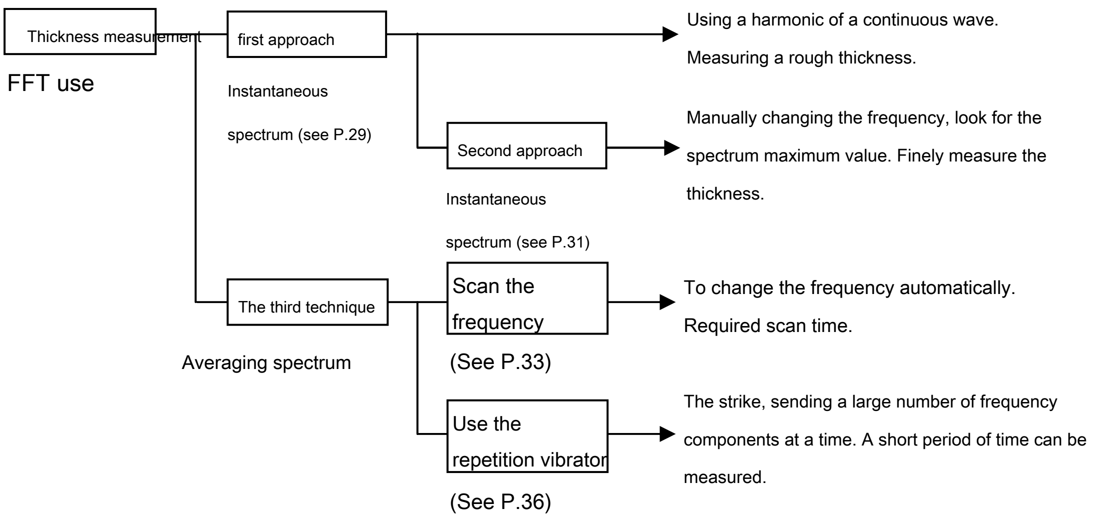
However, because the value at the time of the concrete sound velocity 4000m / s, and asked additional correction of the actual speed of sound.

7-1 for thickness measurement

(1) a method provides an overview of the thickness measurement

The thickness sensor, or repeated transmission wave output from the shaker will be reflected at different boundary acoustic impedances (structure back, internal defects, reinforcement, etc.).

The frequency of the reflected waves from the boundary, by examining using the FFT (please FFT on how to use refer to P.44 "9-2 FFT A Naraiza"), thickness (the distance to the boundary) is you will be asked.



The method of thickness measurement	Use sensor
First approach	Thickness sensor, the thickness of a small sensor, crack-sound velocity sensor
Second approach	Ditto
The third technique (frequency scan)	Ditto
The third technique (repetition vibrator)	Repeat vibrator, thickness sensor

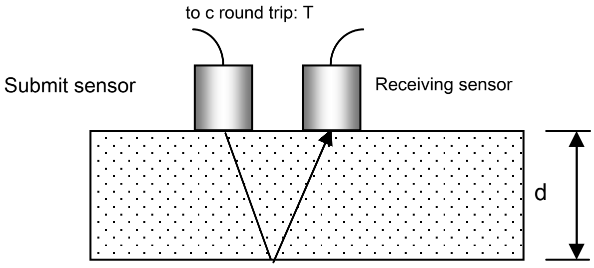
(2) measurement principle

Transmission wave is traveling in the object, time to come back reflected by the face T (s) is the thickness d (m), when the speed of sound and c (m / S), holds the following equation you.

$$T = \frac{2d}{c}$$

In addition, $T = \frac{1}{f}$ From

However, f (Hz): Frequency



Speed of sound: the time required

$$\frac{\quad}{\quad} \quad \frac{\quad}{f}$$

Therefore, the thickness d is

$$d = \frac{c}{2f}$$

It can be expressed as.

Now, when placed side-by-side reception sensor and the transmission sensor, the received signal, the residual vibration and the reflected wave of the transmitted wave it has been synthesized.

Accordingly, they were separated and reflected waves return time (period) in order to extract as its reciprocal is a frequency f (Hz), and using the FFT (FFT on using the P.44 "9-2 FFT analyzer "Please refer to).

When the Fourier analysis of the received wave to the FFT screen of many of the spectrum will appear. The spectrum is equivalent to the thickness of the lowest frequency in the spectrum (slow return time). Spectrum of high frequencies, the residual vibration wave, harmonic, electrical distortion when amplifying the reception wave, and the like reflected wave from the coarse aggregate and reinforcement of positions close, is not required for thickness measurement.

How to determine the speed of sound ※ C

Measurement position and the speed of sound is considered to be the same there, and in the actual thickness is found position, finds the actual speed of sound.

① the actual thickness performs a transmission speed of sound measurement if you can actually measured, such as a scale, we determine the actual speed of sound. Measurement method, please refer to the P.13 "5-2 transmission speed of sound measurement". ② actual measurement can not be, if that can be assumed to be the thickness = actual thickness design

Performs thickness measurement, we determine the actual speed of sound from the following equation. Actual speed of sound c = 2 × design thickness d × frequency f

It should be noted that in the second approach, for El Sonic display value is the thickness, which is translated at the speed of sound 4000m / s, it can make correction in the actual speed of sound.

Correction formula, please refer to P.32 "7-3 second approach (3) Measurement procedure ⑥".

(3) Notes

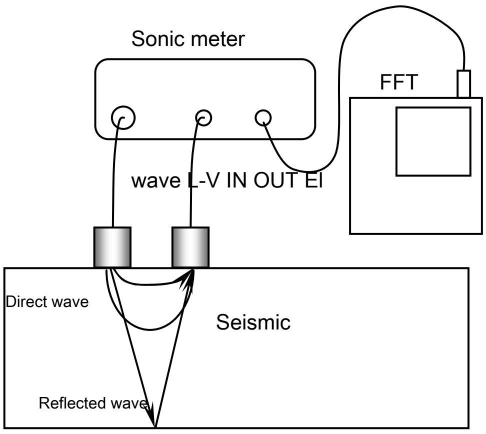
To find the peak of the spectrum, it is important to stabilize the pressure of the sensor to the measurement surface. In the case where the spectral distribution is not obtained satisfactory, it is effective and is pressed against the sensor to the surface.

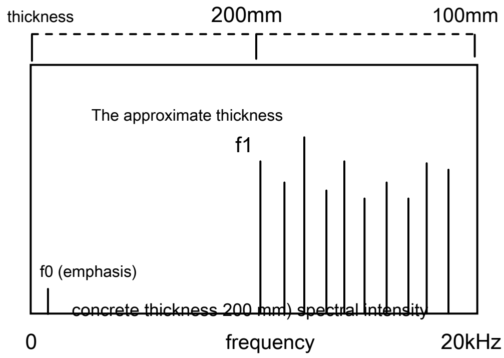
7-2 first approach

(1) Overview

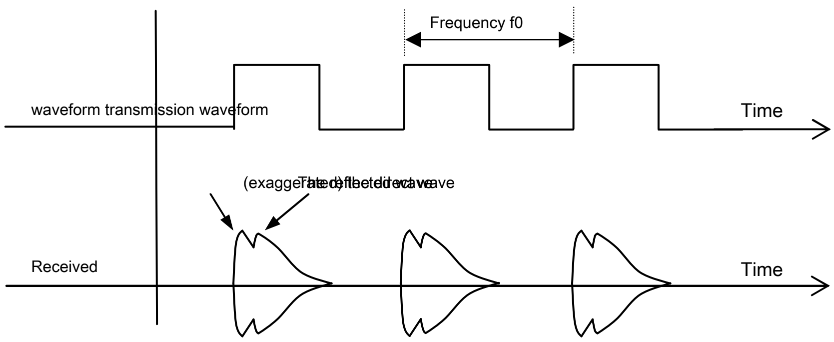
The first approach is can be measured in a short time, the frequency f0 = to transmit a 1kHz continuous wave from the transmitting sensor, which because it captured by higher-order terms of the Fourier series which is based on frequency, corresponds to the thickness the spectrum of the frequency f1 to do not appear only to 1kHz of an integer multiple of the position, the resolution will be lower as the f1 is low (thick).

Also care must be taken so as not to f1 by mistake harmonics.





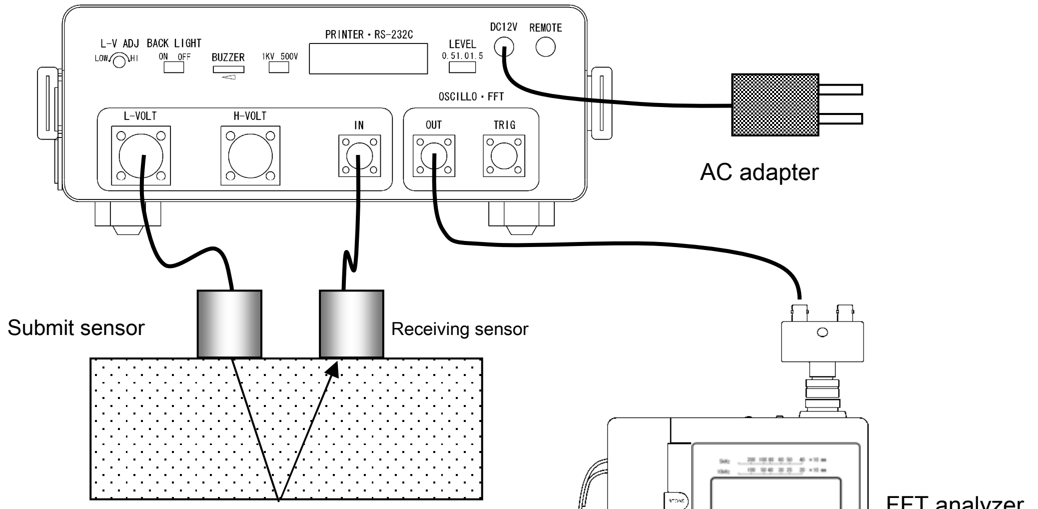
FFT spectral diagram (example

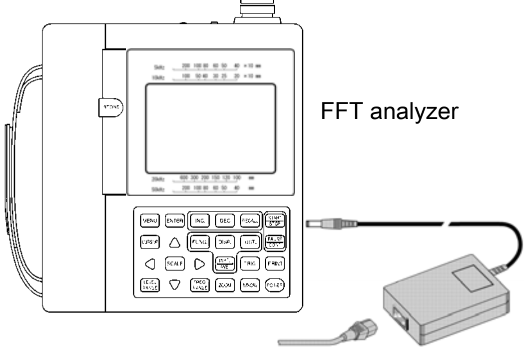


Item	Contents
Use sensors and measurement range (standard)	(Transmission) (Reception) Thickness small sensor — Thickness small sensor: 40 ~ 150 (mm) Thickness sensor — Thickness sensor : 100 ~ 500 (mm) Crack-sound velocity sensor thickness sensor : 500 ~ 1000 (mm)
accuracy	Criterion
Measurement mode	THICKNESS
Meaning of the digital display value	mm lamp lighting: 1 / [calculated at 4000m / s transmission frequency × speed of sound × 1/2 ※ P.31 NOTES "thickness mm display at the time of measurement" reference μSEC lamp lighting: Period of the transmitted wave (= 1 / transmission frequency)
Transmission frequency	1kHz
Configuration	Normal measurement: LV ADJ = HI side maximum (12V) When the crack-sound velocity sensor used to send: LV ADJ = intermediate (6V)

(2) the measurement procedure

① thickness sensor, and connect the AC adapter, the FFT to El Sonic meter.





② El Sonic meter, then turn on the FFT.

Of ③ El Sonic meter <u>SELECT</u> Press the key three times, THICKNESS

lamp is lit, make sure that the 2000 mm (transmission frequency

1kHz) is displayed on the digital display. ④ transmission and

reception of the thickness sensor on the same surface,

Sensor with each other do not contact (sensors of about one minute) arranged in space, you pressed. On the screen of the

⑤FFT it is, and he has a large number of spectral lines.

From ⑥F0 (1 kHz) leftmost (low) than the frequency f1, to or obtains an approximate thickness d (= c / 2f1).

When the spectral distribution is not obtained satisfaction ※

- contact medium or not missing, or not intervening in the sand, or the sensor at an angle is not hit,

<u>Addition</u> Please check and whether not a shortage. - ▲ , ▼ You may try to slightly change the

transmission frequency with the key.

7-3 second approach

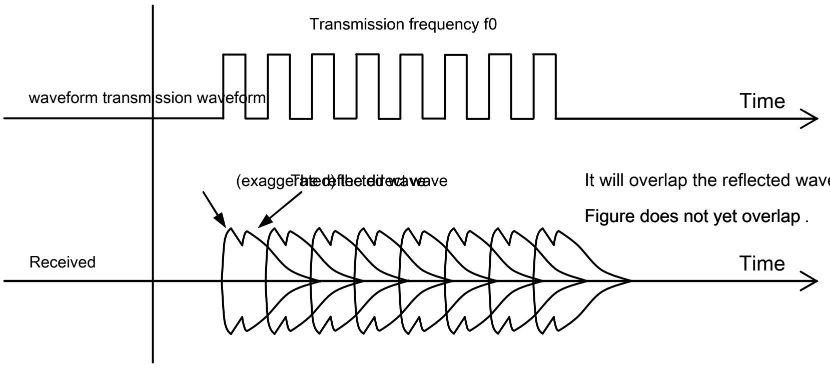
(1) Overview

After the first approach, at a finer resolution in the second approach, and the thickness measurement. The transmission frequency f0▲ , ▼ Varied in the key, in the range of frequency f1 ± 500Hz obtained in the first approach, look for the frequency at which the spectrum is the maximum.

This is the same as the reciprocal of the transmission frequency f0 is the return of the reflected wave time, the reflected wave is superimposed on the direct wave, the spectrum who use to become the maximum.

The thickness will be from the equation P.28 "7-1 (2) measurement principle" as follows.

$$d = \frac{c}{2f}$$



Item	Contents	
Use sensors and measurement range (standard)	(Transmission) (Reception) Thickness small sensor — Thickness small sensor: 40 ~ 150 (mm) Thickness sensor — Thickness sensor : 100 ~ 500 (mm) Crack-sound velocity sensor thickness sensor : 500 ~ 1000 (mm)	
accuracy	± 5% ※ when corrected in the actual speed of sound	
Measurement mode	THICKNESS	
Meaning of the digital display value	mm lamp lighting	μSEC lamp lighting
	1 / [calculated at 4000m / s transmission frequency × speed of sound × 1/2 ※ "mm display at the time of the thickness measurement" following memo column reference	Period of the transmitted wave (= 1 / transmission frequency)
The transmission frequency	**transmission frequency adjustment ▲ , ▼ Variable 1kHz ~ 50kHz in key**	
Configuration	Normal measurement: LV ADJ = HI side maximum (12V) When the crack-sound velocity sensor used to send: LV ADJ = intermediate (6V)	

mm display at the time of the thickness measurement

In a second approach, the transmission will have to change the (continuous wave) frequency, the digital display value has become usual in mm.

This is because they intuitively to obscure, also to the digital display as the thickness of the time of the field in the eyes eliminates the hassle of conversion frequency → thickness, sound velocity 4000m / s in the frequency. Example) 2000 mm in 1 kHz, 40 mm 50kHz transmission conversion equation in: thickness = 1 / transmission frequency × sound velocity 4000 m / s × 1/2

(3) the measurement procedure

It describes as a continuation of the measurement procedure of the first approach.

The frequency range of ①FFT can display f1 obtained in the first approach, reduce to the minimum of the range.

This is, at a finer resolution, is to look for the transmission frequency f0 the spectrum is maximized. (Eg 5kHz <f1 <9kHz → 10kHz range, 9k H z <f1 <19kHz → 20kHz range) of the transmission frequency adjustment of ② El Sonic meter ▼ Press the key, digital display value the first of (mm)

Lower until the approximate thickness was determined by the method (which may be in the readings of the FFT auxiliary scale). The spectrum is a screen of ③FFT will be one. (At the time of the two, the spectrum of the lower frequency

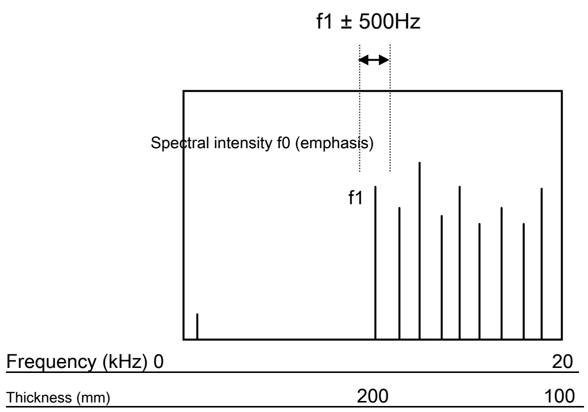
Adopt Le line) while watching the screen of ④FFT ▲ , ▼ Press the key, fine-tune the transmission frequency f0 in the range of f1 ± 500Hz

Then, look for the frequency at which the spectrum is the maximum.

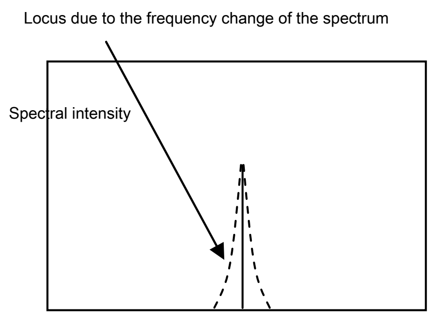
⑤ When you have found the frequency at which the spectrum is the maximum, the digital display value at that time (mm) is, the speed of sound It will be the thickness converted in the 4000m / s.

⑥ If you are corrected by the actual speed of sound, can be calculated with the following formula.

True thickness d (mm) = measured value (mm) × [actual speed of sound (m / s) ÷ 4000 (m / s)]



FFT spectrum view of the first approach



FFT spectrum view of the second approach

※ be varied transmission frequency in a second approach, the change in the spectrum is not observed, or only peak moves to the left or right, when the maximum value of the peak can not be obtained, couplant not insufficient or, if there is no intervention resident of sand, or the sensor at an angle is not hit, please consult one of the or not a pressing shortage.

Transmission frequency adjustment (▲, ▼) key

L- V Koh It is the key to adjust the frequency of the low-pressure continuous wave output from the connector manually.

▲ , ▼ Of key operation

(1) changes by 1mm each time you press. (2) continue to push and make the following motion. ① Press and hold one of the positions will change in a row.

② When the first digit is hold down even if the 8 count change, is the tens place will change. If ③ tens place is hold down even if the 8 count change, the position of the one hundred will change. ④ If you hold down further, hundreds place more will change one count at a time.

⑤ Dono Even when you release once in the state, to return to the (1).

SELECT Re-select the THICKNESS lamp in the key, the display will return to 2000mm.

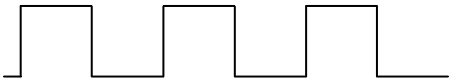
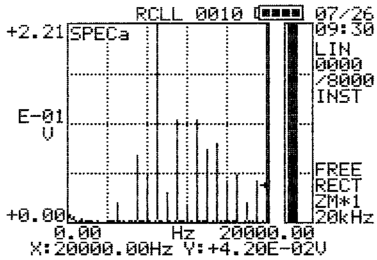
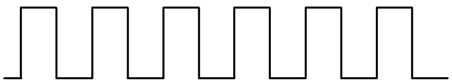
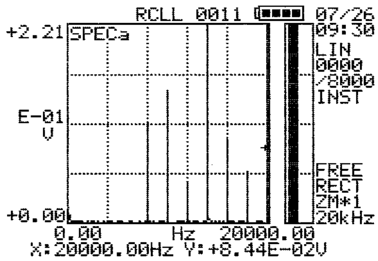
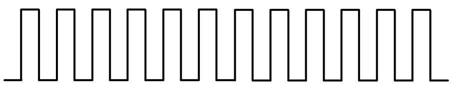
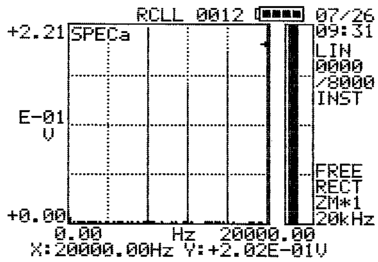
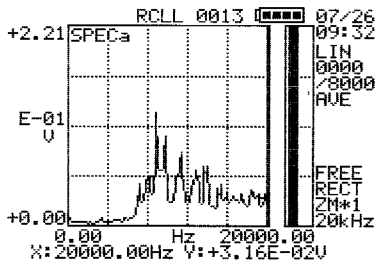
7-4 third technique (frequency scan)

(1) Overview

The received wave by averaging operation by FFT, and obtains the thickness of the peak frequency. Thickness measurement and with a thickness of 300 mm or less of concrete, apply in the case of measuring the reflected wave other than the thickness (rebar or the first time and the inherent cracks measurement).

The transmission frequency up to 1kHz → 4kHz, while automatically changing, adds average computation of the received wave in the FFT.

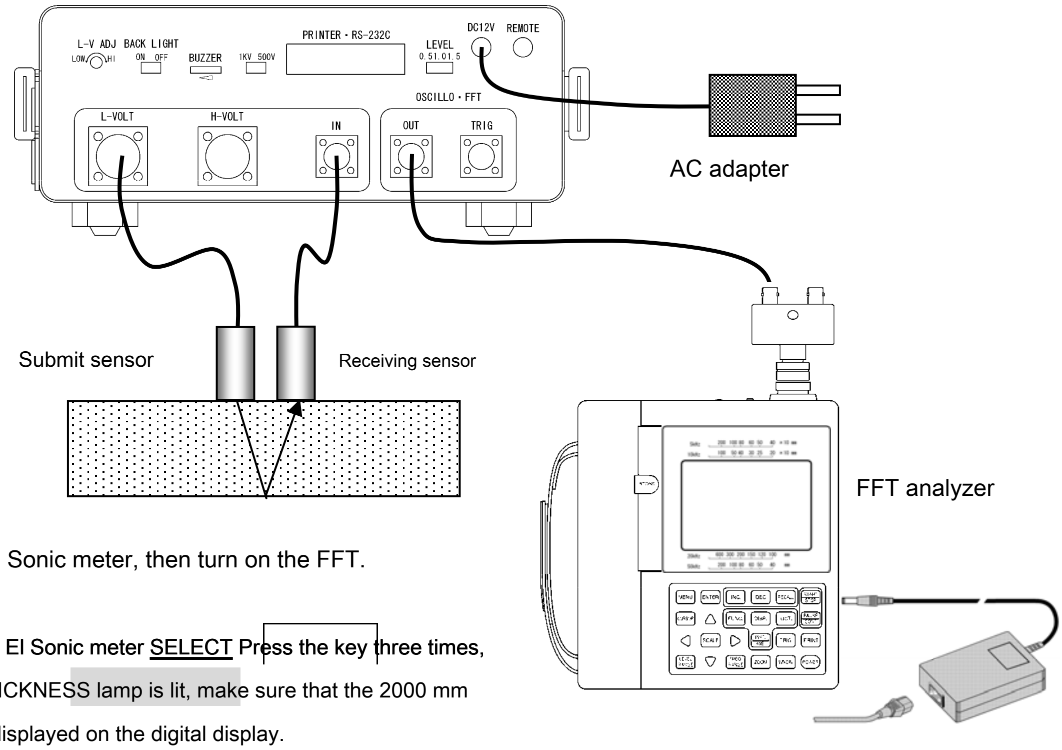
Peak of chevron spectrum diagram obtained by averaging operation is the thickness sought.

	Submit continuous wave (Time-axis waveform)	The received waveform (Frequency axis waveform)
Frequency 1kHz period 1000μs		
Frequency 2kHz period 500μs		
Frequency 4kHz period 250μs		
After the frequency 1kHz → 4kHz scan (after averaging operation)		

Item	Contents	
Use sensors and measurement range (standard)	(Transmission) (Reception) Thickness small sensor thickness small sensor: 40 ~ 150 (mm) thickness sensor Thickness sensor : 100 ~ 300 (mm)	
accuracy	± 5% ※ When calculating the thickness using the actual speed of sound	
Measurement mode	THICKNESS	
Meaning of the digital display value	mm lamp lighting	μSEC lamp lighting
	1 / [calculated at 4000m / s transmission frequency × speed of sound × 1/2 ※ P.3 1 NOTES "mm display at the time of the thickness measurement" reference	Period of the transmitted wave (= 1 / transmission frequency)
Transmission frequency	SCAN Automatic key change 1kHz → 4kHz	
Configuration	Normal measurement: LV ADJ = HI side maximum (12V) When the crack-sound velocity sensor used to send: LV ADJ = intermediate (6V)	

(2) the measurement procedure

① thickness sensor, and connect the AC adapter, the FFT to El Sonic meter.



② El Sonic meter, then turn on the FFT.

Of ③ El Sonic meter SELECT Press the key three times, THICKNESS lamp is lit, make sure that the 2000 mm is displayed on the digital display.

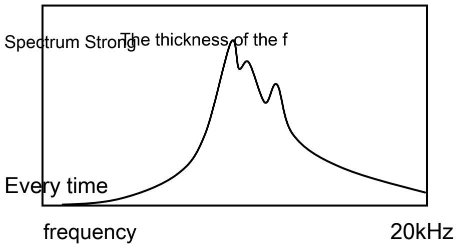
Set to allow averaging operation in ④FFT.

⑤ transmission and reception of the thickness sensor on the same plane, side-by-side at intervals of interval sensor with each other do not come into contact with - sensor about one minute, and pressed. Press the START / STOP key of the averaging operation of ⑥FFT. In the FFT screen in this operation, reception A wave Averaging the calculated results are continuously displayed. ⑦ At the same time, of El Sonic meter SCAN Press the key.

Digital display value in this operation will continue to decreasing continuously (transmission frequency is increased). ⑧ display value Make sure that the stationary (scan stop) at 500 mm (transmission frequency 4kHz).

⑨ At the same time, press the FFT of the START / STOP key to end the averaging operation. ⑩ you can make analysis with the result (the spectrum of the arithmetic mean). Peak f of the low frequency in the FFT display shows the thickness seek.

The spectrum of the averaging method



(Example)

When the peak value of the spectrum and when the sound velocity c = 4000 (m / s) of 10.4KHz, from d = c / 2f

The measured value d = 4000 / 2f = 2000 / 10.4 = 192 mm

Other of the spectrum

Spectrum of less than f frequency (left): this also is small measured reflected waves from distant parts than the thickness

There is a door.

The spectrum of higher than f frequency (on the right): represents the reflected waves from the portion closer than the thickness.

7-5 third technique (repetition vibrator)

(1) Overview

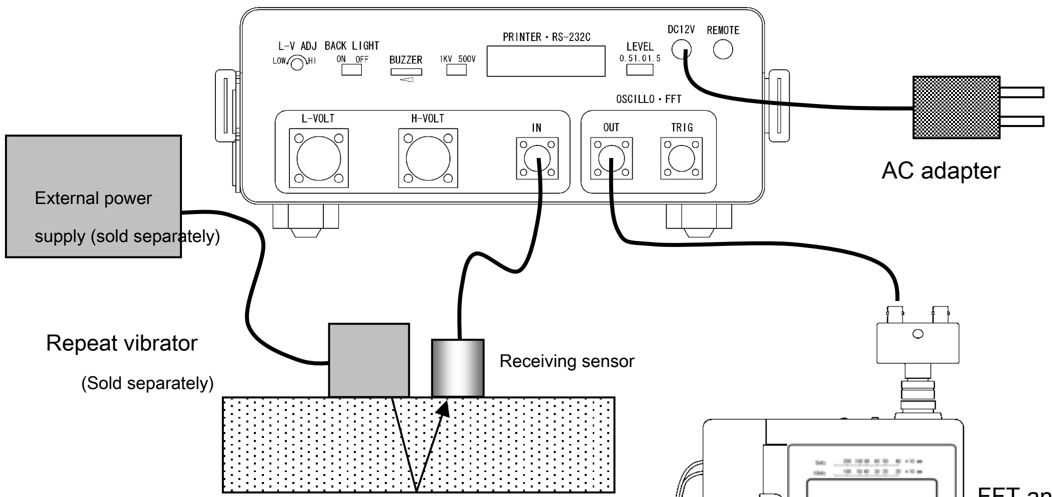
For the thickness of 300mm or more measurements, in place of transmission sensors, by using the repetition vibrator, without scanning the frequency it can be done a third approach. By the blow, it is possible to send a large number of frequency component at a time, it can be measured in a short period of time.

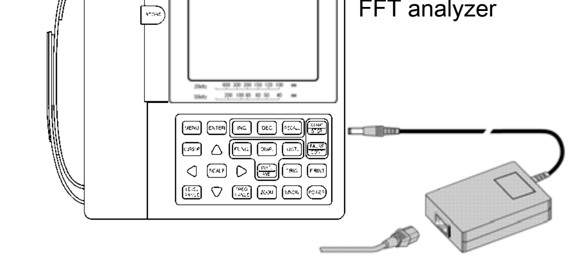
Item	Contents
Use sensors and measurement range (standard)	(Transmission) (Reception) Repeat vibrator thickness sensor: 300 ~ 1000 (mm) When ~ 2000 (mm) conditions are good
accuracy	± 5% ※ When calculating the thickness using the actual speed of sound
Measurement mode	Not selected (measurement mode lamp all off)
Transmission frequency	-
Configuration	-

(2) the measurement procedure

① thickness sensor, and connect the AC adapter, the FFT to El Sonic meter.

In addition, connect the repetition shaker to an external power source.





② El Sonic meter, then turn on the FFT. Set to allow averaging operation in ③FFT. ④ repeating vibrator and the receiver sensor on the same surface,

Parallel at the contact does not interval (sensor about 1 minute) base, you pressed.

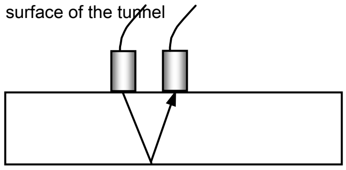
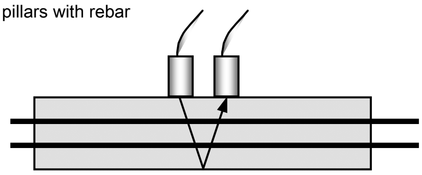
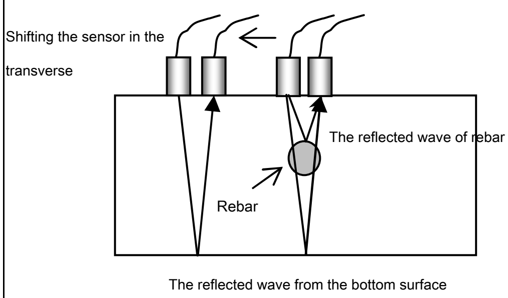
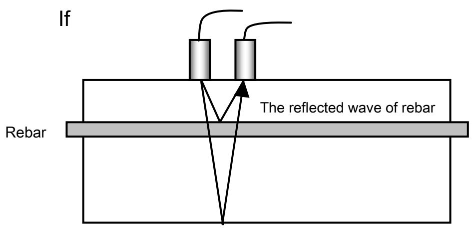
⑤ Turn on the power of repetition shakers.

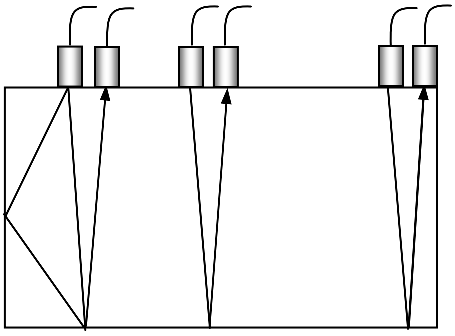
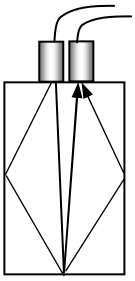
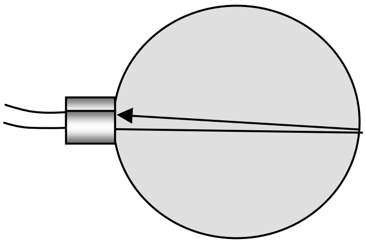
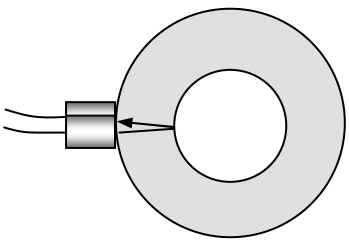
⑥ At the same time, press the START / STOP key of the averaging operation of the FFT. Screen of the FFT in this operation

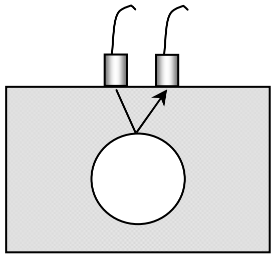
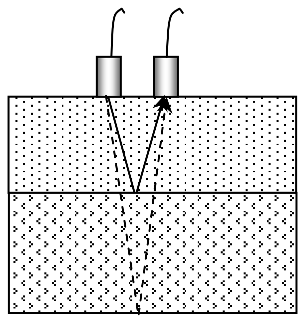
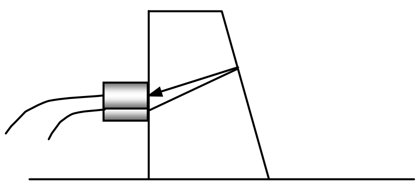
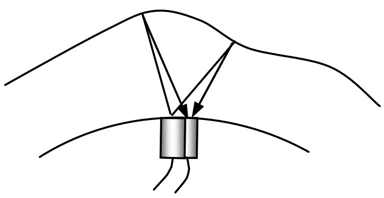
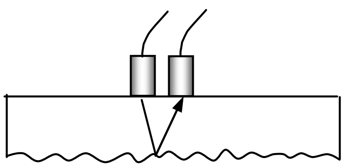
In, as a result of averaging the Fourier spectrum it will be continuously displayed. When it is no longer seen is a change in the spectrum of ⑦FFT screen, press the START / STOP key, adding flat

To end the average operation, turn off the power of repetition shakers. Low frequency of the peak f in ⑧FFT display shows the thickness to be obtained.

View of the thickness measurement and results in 7-6 various circumstances

Situation and the reflected wave	Description
① wide thickness measurement of the floor panel and the wide surface of the tunnel 	- Front and back with no irregularities, the thickness measurement of a wide plane It is can be measured without any problems. - Those from the reflected wave back opposing surfaces (equivalent thickness) is.
② thickness measurement of a wide structures and large pillars with rebar 	- The thickness sensor, the spectrum of rebar is a large number Yes of in the spectrum, can not be determined, the thickness of the floor panel is measured as the lowest frequency. - Small thickness when measuring the distance to the rebar Use the sensor. In that case, it can not thickness measurement of thick floor board.
③ measurement of the head thickness and position of the rebar (A) place by arranging a sensor at a right angle to the rebar If  (B) If that were side-by-side parallel to the sensor in the rebar If  	- In the rebar with a diameter of 22 mm, 70 mm to 90 mm or depth In can be measured. - For rebar measuring, using a thickness smaller sensor please. - Position is at right angles to align the sensor to the rebar But it can be measured even in parallel - Oko measured by shifting the sensor position little by little You can see the rebar position by Nau. Note) In the thickness sensor, the thickness of the concrete is measured Can you, but rebar can not be measured.

Situation and the reflected wave	Description
④ thickness measurement of the end of the floor panel  Reflected wave edge reflection wave thickness	- The thickness measurement of the end portion of the floor panel, is reflected by the bottom surface Was in addition to the wave, is also measured wave was re-reflected on the end face. - These lower spectrum corresponds to the thickness circumferential In the wave number, it is observed will as a small spectrum. Basically, those who avoid the measurement of the end is no flame. - If complete end of the re-reflected wave problem Although there is no non-uniformity of the material in the vicinity of the surface will affect.
⑤ narrow structure width than thickness, the round bar type Height measurement of the test piece 	- Of short pillars and concrete test pieces of the length The length measurement, can not be separated by a reflected wave of the reflected wave and the bottom surface of the side surface interference, the length is measured slightly (10% to 30% by the situation) long. - When we produce a thickness measurement for the test of the concrete Huang, please as a guideline the width> thickness × 3.
⑥ diameter measurement of round reflection surface 	- The shortest distance (straight to a plane perpendicular to the measuring point Diameter) will be measured.
Thickness measurement of ⑦ telephone pole or pile 	- The reflected wave is from the inner side of the counter surface.

Situation and the reflected wave	Description
⑧ measure head thickness of the pipe in the concrete 	- You can measure the distance to the surface of the cavity. - Measurement of a small cavity in a deep position is difficult It is.
⑨ thickness measurement of the concrete of the two layers of the edge cutting a plastic sheet 	- The thickness of up to edge cutting by a top with a plastic sheet It is will be measured. - When good adhesion of vinyl sheet portion, There is also the case that the total thickness of up to the lower side can be measured.
⑩ measuring the thickness of the oblique facing surfaces such as inclined wall Constant (when the back surface and the surface are not parallel) 	- Thickness measurements to the measurement surface not parallel reflecting surfaces In, shortest distance is measured up to a plane perpendicular to the measurement point.
⑪ structure has large irregularities on the back surface (an Part thickness measurement of the tunnel, etc.) 	- ⑩ the same reasons, FFT spectrum plural There is a case to be displayed.
There is a small irregularities, such as cobble stone to ⑫ bottom Thickness measurement such as a floor panel 	- Measurement is possible, but the spectrum because of the irregular reflection It will be smaller.

Chapter 8, detection of internal defects

By using the method of transmission speed of sound and thickness measurement, you can check the quality of the internal concrete structure.

Using a 8-1 transmission speed of sound measurement

(1) detection method

To determine the soundness by comparing the measurement results of the investigation section and the healthy

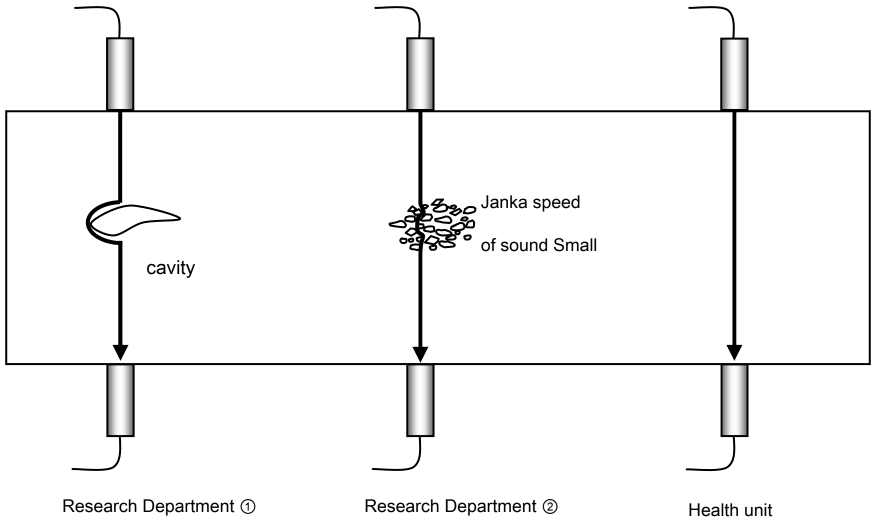
part. Research Department: part a defect is suspected be surveyed

Sound part: Research Department and Haisuji, shape, out of place, such as hitting 設時 period are the same conditions, it is assumed to be healthy

Part that

Measuring both of these ultrasonic wave propagation time (when the propagation distance and survey unit is different, in terms of the speed of sound), then compared.

Below is diagram schematically illustrating the propagation path of the wave initially reaching the receiving sensor. Cavity, if there is such as Janka, ultrasound or bypassed as shown in the figure below Investigation Department ①, in order to pass through the place the sound velocity is slow as Research Department ②, long propagation time compared to the healthy part (speed of sound It is slow) of Ri you.



Schematic view of the ultrasonic propagation paths

(2) Notes

When using a transmission speed of sound measurement can not distance estimation to the internal defect position. When measuring the distance to the internal defect position, see next page.

Using a 8-2 thickness measurement

(1) detection method

Like the case of using a transmission speed of sound measurement, it performs a comparison with the spectrum of the sound portion. Below is diagram schematically showing the reflected wave propagation paths corresponding to the thickness of each situation.

Void (cavity, peeling, Janka) is, when minor (below survey unit ①)

Since the ultrasonic wave is reflected by the concrete back to bypass the gap, reflection time will be longer in comparison with the healthy part. The presence or absence of internal defects you can see, but can not be used to determine the depth of up to defect.

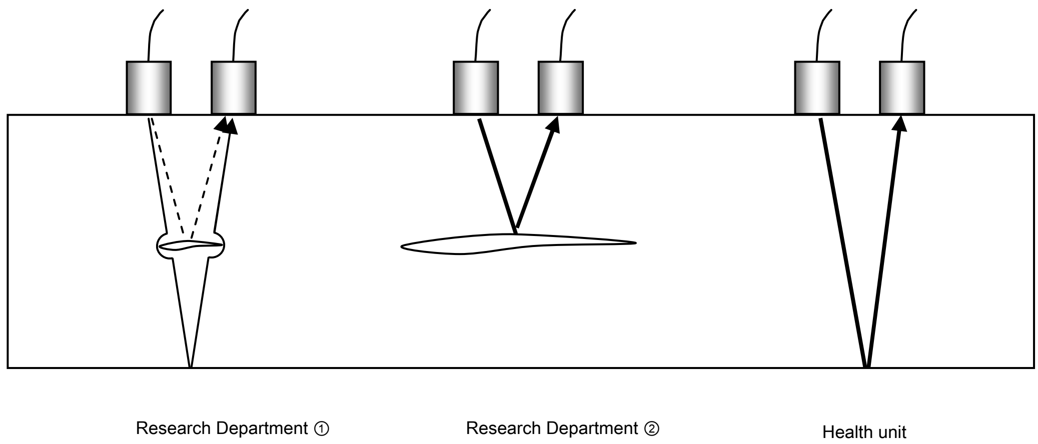
... low frequency f1 as compared to the healthy part, measured the thickness d is large

※ When there is a reflected wave from the void surface, to determine the spectrum of frequencies higher than f1, the gap

You may be asked to depth to the surface.

Void if (cavities, exfoliation, Janka) is significant (figure investigation unit ②)

Since ultrasound is reflected at the air gap surface, before space surface depth (thickness) is required. ... high frequency f1 as compared to the healthy part, measured the thickness d is small



Schematic view of a reflection wave propagation path

Connection with the Chapter 9 peripherals

9-1 printing printer

(1) Application

Crack depth measurement (digital method, a short distance detour wave method), and digital display value printed during speed-of-sound measurement

(2) Product Overview (recommended product)

Manufacturer: Corporation Mitutoyo

Model : DP-1VR

Accessories: one for El Sonic communication cable, one AC adapter, the recording paper, Volume 1,

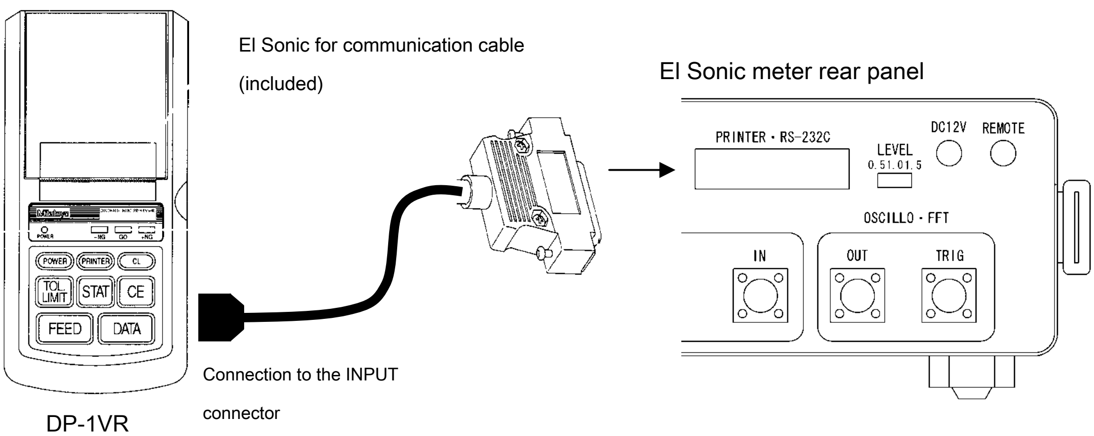
Instruction Manual Part 1, Quick Reference 1 part of one strap

specification : For more information please refer to the instruction manual of DP-1VR.

Item	Contents	Remarks
Printing method	Thermal line 384dot printing	
speed 0.5 sec /	line	When using the AC adapter
Print line number 1	2000 lines / Volume 1	
power	AC adapter (6V, 500mA) 4 AA alkaline batteries	AC100V ± Yes, even within 5% Ni-MH
Operating tempera	ture 0 ~ 45 ℃ / 10 ~ 45 ℃	AC adapter / battery
Size Vertical 201.1	× horizontal 94 × thickness 75.2mm Weight	
	390g	only a main part

(3) connection

El Connect with sonic meter on the rear panel of PRINTER · RS-232C connector and DP-1VR the Eruso nick for communication cable (included with the DP-1VR). · DP-1VR, you can use the battery, either AC adapter.



(4) How

· Print printer POWER Turn on the power by pressing the key, make sure the lighting of the POWER lamp.

El Sonic meter PRINT When you press a key or a foot switch (sold separately), the value of the digital display is printed.

• When this, if the display of El Sonic meter of mm, but "mm" after the number is printed, in the case of μSEC, nothing after the numeric indicia It is shaped not. • To OFF the power to the DP-1VR is, POWER Please press and hold the key for 2 seconds. ※ For more information please refer to the instruction manual of DP-1VR.

Note) during the measurement of El Sonic meter μSEC / mm When you press the key, "* NO GAGE *" and is marked character, an error will occur. In this case, the DP-1VR CL Press the key, Please cancel error.

(5) Communication cable connection diagram

DP-1VR side 10pin Pin No.		El Sonic meter side Pin No. D-sub25pin	
A1	—	7	FG
B1	—	12	DATA
A2	—	13	CLOCK
B2	—	14	READY
A3	—	15	REQUEST

9-2 FFT analyzer

(1) Application

Thickness measurement, and the reception wave frequency analysis upon detecting internal defects

(2) Product Overview (recommended product)

Manufacturer: Rion Co., Ltd. Model

: SA-78

Accessories: BNC 1 cables, one AC adapter, single 2 alkaline batteries 4, 2ch

One input conversion adapter, one Compact Flash, one storage case, easy easy instruction manual Part 1,

CD-ROM version of the instruction manual (with a data monitor software) one

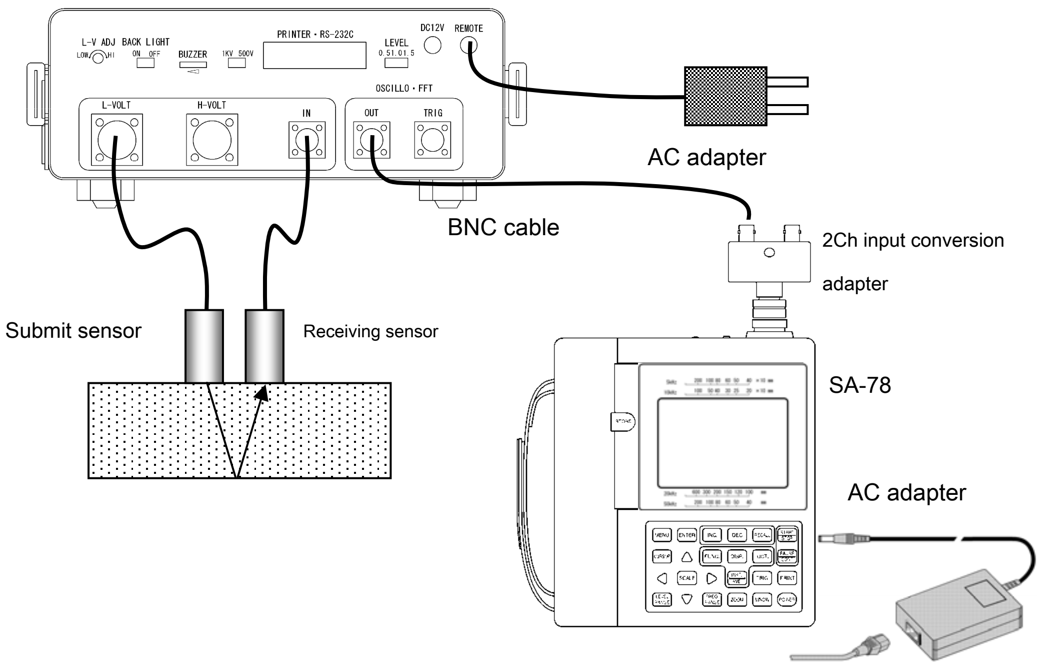
Configuration : P.47 Please refer to the "Settings for (6) thickness measurement". specification

: For more information please refer to the instruction manual of SA-78.

Item	Contents	Remarks
Operating temperature	0 ~ + 40 ° C.	
Humidity	20 ~ 90% RH	Non-condensing
Power supply	AC adapter or a single-2 type batteries 4	
Size	Width 156 × height 174 × thickness 45.7mm	Excluding protrusions
mass	About 900g	Including batteries

(3) connection

And reception signal of El Sonic meter as shown in the figure below the 2ch input conversion adapter (rear surface of the OUT connector) and the SA-78 (Ach) Connect a BNC cable (included with the SA-78). · SA-78, you can use the battery, either AC adapter.

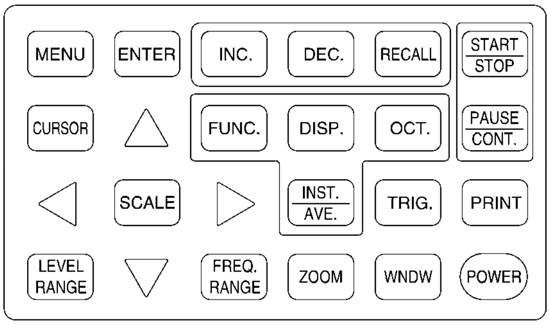


(4) The main key operation

It describes the main key operations to be used in the thickness measurement below.

Detailed features, how to operate, refer to the instruction manual of SA-78.

Operation panel key of the SA-78



① power

POWER: Press and hold for more than 2 seconds, the power is ON, and OFF.

② display screen and measurement conditions set

FUNC:. Open the function settings window.

▲, please select the SPECa / SPECb in ▼ key. Close the Settings window by pressing again FUNC. Key. DISP.

: Each press, you can make display switching of the two functions that have been selected in the function setting window. Please in the first graph display of SPECa. MENU: to enter the main menu screen.

In addition ▲, ▼ select an item in the key, the process proceeds to each menu screen and press the ENTER key, you can make settings such as measurement conditions.

③ measurement start, stop

INST./AVE. : Switches the data to be displayed on the graph. INST. The first in the instantaneous value data, and then use the second approach. AVE. Will be used in the third method in the averaging calculation data.

START / STOP :. AVE when the mode you can make start / stop of the averaging operation.

PAUSECONT. : When pressed during measurement screen display, data in the graph is paused. When pressed during averaging operation, the operation is paused. Press again, it will be resumed.

Saving ④ data, read, print

STORE: the memory card (compact flash card), measurement data, setting conditions and the date and time

Save the like.

In addition the data stored in the memory card can be displayed in FFT, for the format of the file is CSV format, it is possible to perform processing on PCs using generic spreadsheet software.

RECALL: Press when reading the data stored in the memory card. Measurement and press again

It will return to the constant

screen. INC. : At the time of measurement, change the store destination address number (+1). At the time of reading, to change the address number that is stored (+1). DEC.

: At the time of measurement, change the store destination address number (-1). At the time of reading, to change the address number that is stored (-1). PRINT: printer connected and the displayed measured graph or a menu screen display to the outside

It prints on the DPU-414 (sold separately).

Display range switching of ⑤X axis

FREQ.RANGE: Open the Settings window.

◀ , ▶ Frequency range of the set value in the key and select (5kHz, 10kHz, 20kHz, 50kHz) a.

Close the Settings window by pressing the FREQ.RANGE key again. The following table is an estimate of each frequency range and application thickness of the case in terms of concrete speed of sound 4000m / s.

Frequency range	Measure of the applied thickness
50kHz	40 ~ 150mm
20kHz	100 ~ 300mm
10kHz	200 ~ 500mm
5kHz	400 ~ 2000mm

Display range switching of ⑥Y axis

SCALE : Press and will be the scale can be changed state. ▲, ▼ expand the Y-axis display area in the key, and then reduced.

LEVEL RANGE: Open the Settings window.

◀ , ▶ The set value of the level range in the key (+ 20dB, + 10dB, 0dB, -10dB) is selected, and then adjust the spectral intensity. Close the Settings window by pressing the LEVEL RANGE key again.

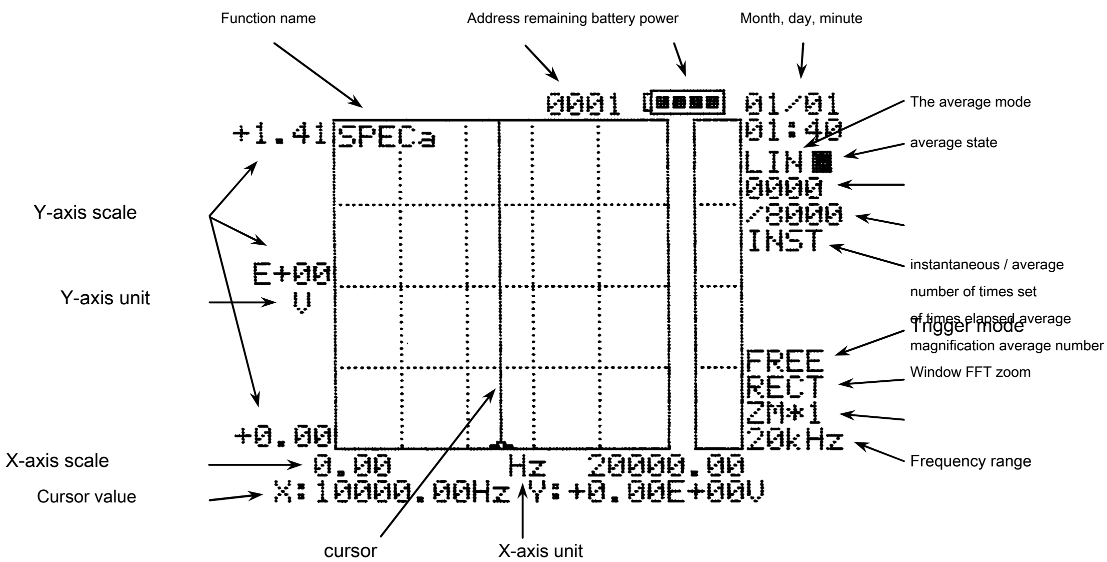
⑦ Other

CURSOR : Each time the button is pressed, a single cursor, two cursor (individual movement), two cursor (interlocking movement), two cursor (individual movement, one of the overall value) will switch to the order of.

At the time the individual move ▲, make a selection of a moving target cursor in the ▼ key (switching).

◀ , ▶ It is displayed the solid line of the cursor moves to the graph key, X value at the cursor position and the Y value are displayed.

(5) Description of the measurement screen



(6) set for thickness measurement (Dong-Hermes factory setting)

※ the initial setting of the manufacturer (Heraklion) (factory settings) is different double-underlined part.

Key Settings

INC.DEC	: Address 0001
FUNC.	: SPECa / SPECb
DISP.	: 1 graph (SPECa)
OCT.	: Not the octave synthesis
INST./AVE.	: INST.
LEVEL RANGE	: 20dB
FREQ. RANGE	: 20 kHz
ZOOM	: × 1
WNDW	: RECT
TRIG.	: FREE (OFF setting)

MENU Settings

INPUT menu (Ach & Bch)

COUPLING	: AC
CCLD	: OFF
LPF	: OFF
HPF	: 100Hz

ANALYSIS menu

CROSS-SPEC	: ON
REF CH	: Ach
AVERAGE DOMAIN	: FREQ
AVERAGE MODE	: LIN
AVERAGE TIMES	: 8000

DISPLAY (1) menu

SPEC OPE	: OFF (Ach & Bch)
FREQ WEIGHT	: OFF (Ach & Bch)
PARTIAL OVER ALL	: OFF

DISPLAY (2) menu

Y-AXIS	: LIN
Y-VALUE	: 0-PEAK
PEAK LIST	: OFF

CALIBRATION menu

CALIBRATION MODE	: OFF
TRANSFER VALUE	: If the CALIBRATION MODE is of LIN 1 EU = 1 V (Ach & Bch) If the CALIBRATION MODE is dB 0 dB EU = 0 dBV (Ach & Bch)
REFERENCE VALUE	: 0 dB EU = 1 EU (Ach & Bch)

TRIGGER menu

TRIGGER MODE	: SNGL
TRIGGER SOURCE	: INT
TRIGGER POSITION	: +0
TRIGGER CH	: Ach
TRIGGER SLOPE	: +
TRIGGER LEVEL	: +8 / 16

STORE menu

CARD INITIALIZE	: OFF
STORE FOLDER	: STRBLK1
DISPLAY FILES	: OFF
SELECT FILE	: According to the FILE present in the memory card
DELETE FILE	: OFF

SETUP MEMORY menu

SETUP MEMORY No.	: 1
SAVE	: OFF
LOAD	: OFF
DELETE	: OFF

DATE / TIME menu

DATE	: Not set
TIME	: Not set

9-3 FFT for printer

(1) Application

Printing of the FFT screen

(2) Product Overview (recommended product)

Manufacturer: Seiko Instruments Co., Ltd. Model

: DPU-414

Accessories: RS-232C straight one cable, one AC adapter,

One battery pack, recording paper, Volume 1, Instruction Manual Part 1

specification : Please refer to the instruction manual of the DPU-414 for more information.

Item	Contents	Remarks
Printing method	Thermal serial dot system Printing	
speed	up to 52.5cps	Normal character
Power supply	AC adapter (6.5V, 2A) battery pack (Ni-MH)	
Operating temperature	0 ~ 40 ℃	
Humidity	30 ~ 80% RH	Non-condensing
size	Width 170 × depth 160 × thickness 66.5mm	
mass	580g	Not included battery pack

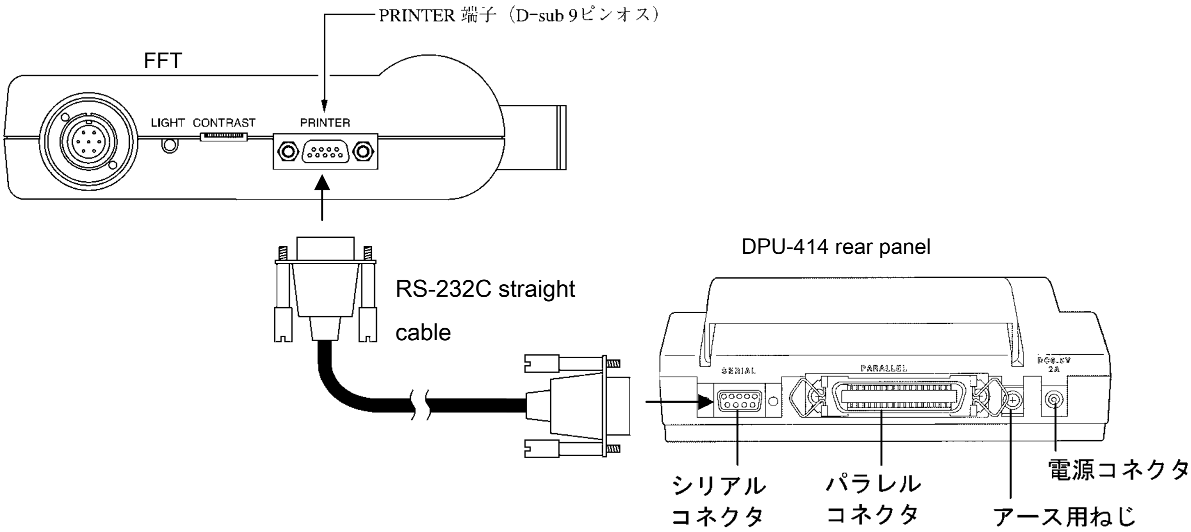
Setting: Factory setting

	Software DipSW SW-1		
		SW-2	SW-3
1	OFF	ON	ON
2	ON	ON	ON
3	ON	ON	OFF
Four	OFF	ON	ON
Five	ON	ON	OFF
6	OFF	ON	ON
7	ON	ON	ON
8	ON	ON	ON

(3) connection

· FFT and a DPU-414 (SA-78) Connect with RS-232C straight cable (supplied with the DPU-414).

· DPU-414 can be used battery, either AC adapter.



※ There is the FFT (SA-78) Instruction Manual P.24 of the "use the included conversion adapter," but, to the DPU-414 for Eruso Nick, conversion adapter is not included. Since the both ends comes with a 9-pin to 9-pin RS-232C straight cable, conversion adapter is not required.

(4) How

· FFT (SA-78), and ON the power of the DPU-414. · DPU-414 on the line Make sure the lighting of the lamp. · FFT of (SA-78) PRINT When you press the key, you can print a hard copy of the display screen. ※ For more information, please refer to the instruction manual of the DPU-414.

(5) connecting cable wiring diagram (straight)

D-sub9pin	Pin No.		Pin No.	D-sub9pin
	1	—	1	
	2	—	2	
	3	—	3	
	Four	—	Four	
	Five	—	Five	
	6	—	6	
	7	—	7	
	8	—	8	
	9	—	9	
	flame	—	flame	

<u>9-4 oscilloscope</u>

(1) Application

Observation of the transmission trigger output, and the received signal amplifier output waveform

(2) Product Overview

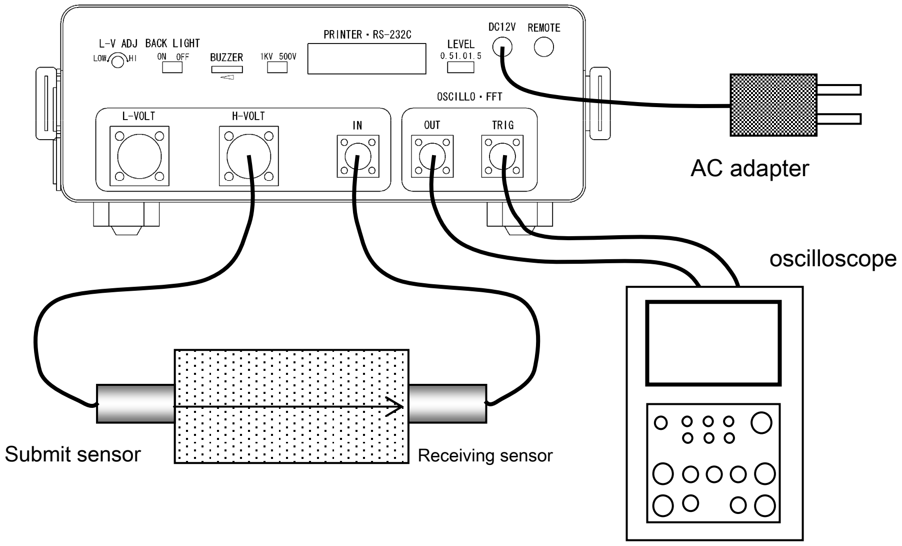
Manufacturer, model : If you meet the following specifications, there is no particular designation

specification : 2ch, more than 20M samples / s recommended

(3) connection

As shown in the figure below, the trigger output of El Sonic meter (TRIG), the amplifier output (OUT) connector and an oscilloscope (at the time of purchase from our company comes with the oscilloscope) BNC cable to connect with.

(Connection example: when the speed of sound measurement)



(4) set

Setting ① trigger

Trigger Source: ch enter the TRIG signal SWEEP: NORMAL

SLOPE: + COUPLING: DC Trigger Level: 300 mV before and

after ② voltage, setting of the time axis (approximate)

Voltage axis: 2V / DIV time axis:

10μs / DIV ~

※ operation method, please refer to the oscilloscope of the instruction manual.

9-5 foot switch

(1) Application

Printing printer, or PC contact To continue time Output the value displayed in the digital display in RS-232C communication ※ El Sonic meter PRINTER This is the same function as the key.

(2) Product Overview (recommended product)

Manufacturer: Dong-Hermes Co., Ltd.

Accessories: No Specifications

:

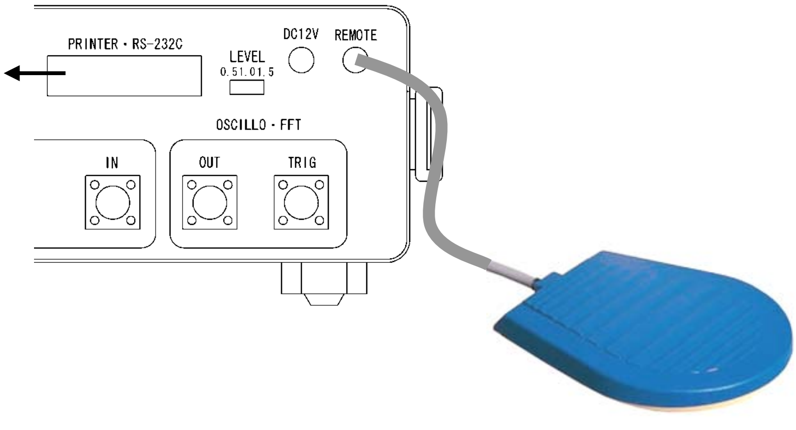
Item	Contents
Contact configuration	1a
Behavior	Momentary
Operating force	9.8 (N)
Operating temperature	- 5 ~ 40 ℃
Humidity	Less than 85% RH
Withstand voltage	AC500V / min
Size	Vertical 121 × horizontal 96.5 × thickness 13.5mm
mass	190g

(3) connection

Connect the foot switch on the rear panel of the REMOTE connector.

El Sonic meter rear panel

To print a printer or PC



Foot switch

(4) How

• When the measured value is stable, press the foot switch.

El Sonic meter (rear panel of PRINTER · RS-232C connector) from the printing printer, or data to the PC will be sent.

9-6 PC (RS-232C)

(1) Application

External personal computer (hereinafter: PC) read digital display value to, and measurement mode switching from the PC

(2) Connection

Connect the El Sonic meter PRINTER · RS-232C (D-sub25 pin) connector and a PC RS-232C port of in RS-232C cross cable (included with the El Sonic meter).

(3) RS-232C communication parameters

Parameters	The set value
Transfer system	Asynchronous method
baud rate	2400
Data length	8bit
Stop bit length	1bit
Parity check	None

(4) communication protocol

Data request from the PC (handshaking - Subdivision: Yes)

Transmission from the PC	Reply of El Sonic
"S" + CRLF	* * * .* Us
"M" + CRLF	* * * * Mm

Measurement mode switching from the PC (handshaking - Subdivision: None)

Transmission from the PC	El Sonic measurement mode of
"C" + CRLF	CRACK
"T" + CRLF	TIME
"H" + CRLF	THICKNESS

El data transfer from the Sonic (handshake - Subdivision: None)

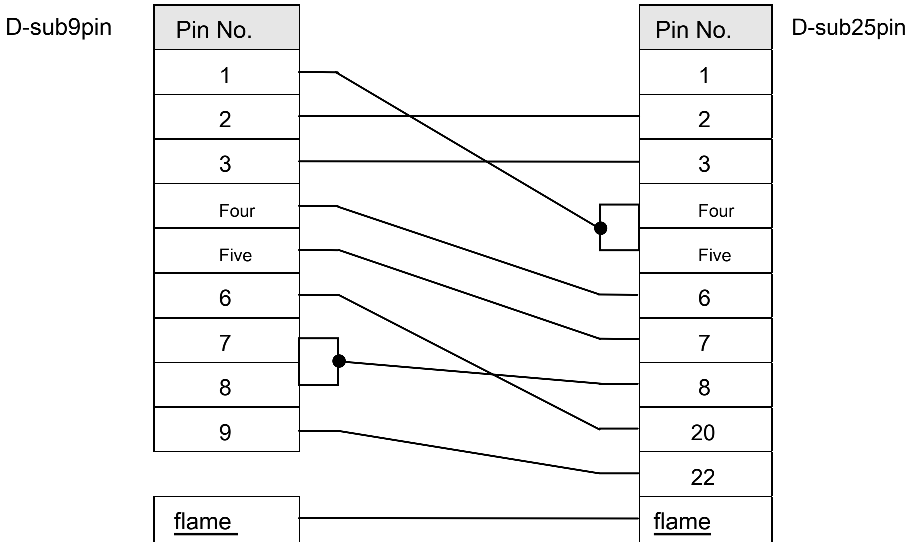
Submit to the operation PC in El Sonic
PRINTER Display LCD display press the key (***. * Us or **** mm)

(5) ELSONIC-Excel read sample program

It comes to El Sonic meter. Connect the RS-232C cross cable, PRINTER Simply press the key, you can display on Excel the digital display value.

Please refer to the operating instructions that came with the details sample program.

(6) RS-232C cable wiring diagram (cross)



Chapter 10 Specifications

10-1 Specifications

Content	Crack depth measurement	Speed of sound measurement	Thickness measurement
range of measurement (Approximate)	5 ~ 30mm (Cracking a small sensor) 30 ~ 500mm (Crack-sound velocity sensor) 400 ~ 1500mm (Cracking powerful sensor)	0.1 ~ 999.9μs (digital display)	40 ~ 1000mm When ~ 2000mm ※ condition is good
Measurement accuracy	± 5 mm (Flat surface depth 5-30 mm) ± 10 mm (Depth 30 to the flat surface of 150 mm) ± 10% (The flat surface of the depth of 150 ~ 1500mm) ※ when measured in the lamp method	± in the length 250 mm 0.3μs ※ repeatability of the same concrete surface	± 5% Calculated thickness using the actual speed of sound ※, or when corrected
Acceptable use conditions	Temperature: 0 ~ + 40 ℃ Humidity: 80% RH or less (however, no condensation)		
Power supply	AC adapter (AC100V 50/60 Hz, accessories), or AA batteries 8 (accessory), or an external power supply (optional) The power supply voltage range: DC10.8 ~ 15.0V Current consumption: about 0.5A (crack-sound velocity sensor connection time CAL operation, H-VOLT voltage pulse 1KV, backlight ON, buzzer volume maximum, RS232C communication, at the rated voltage 12V)		
Size	El Sonic meter: width 240 × height 105 × depth 245mm Sensor other dimensions, please refer to P.59 "10-4 Dimensions"		
mass	El Sonic Meter: 3.2 kg, crack-sound velocity sensors: 0.4kg, cracked a small sensor: 0.2kg cracking powerful sensors: 0.8kg, the thickness sensor: 0.7kg, thickness small sensor: 0.3kg, repeatedly vibrator: 0.5kg , FFT analyzer: 840g		

※ FFT analyzer, and sold separately specifications of each product described part of the "connection to the Chapter 9 peripheral equipment" (external power supply P.9), or please refer to the instruction manual. Measurement

10-2 of ultrasonic sensor types and applications

In the measurement of the measurement and the thickness of the crack depth is different sensors.

Sensor name, dimensions, appearance	Use	The nominal frequency	Features - Remarks
Crack-sound velocity sensor φ20 (vibration surface) × L125 mm 	Crack depth measurement cracking depth: use in Oyo its 30-500 mm Speed of sound measurement Thickness measurement thickness: used to send Sensor of approximately 500 ~ 1000mm	28 kHz	And output is large and transparency large · CAL value of about 13.0μs
Cracking small sensor φ12 (vibration surface) × L60 mm 	Crack depth measurement cracking depth: use in Oyo its 5 to 30 mm	200 kHz	· Output Small-permeable small-CAL value of about 0.4μs
Cracking powerful sensor φ35 (vibration surface) × L95.5 mm 	Crack depth measurement cracking depth: used to send sensor of Oyo its 400 to 1500㎜ Using long structure of sound velocity measured propagation distance	5 kHz	· Output is extremely large, the transmission-reception sensors, about CAL value, using the crack-sound velocity sensor 10.3μs
Thickness sensor φ28.5 (vibration surface) × L73 mm 	Thickness measurement thickness: Approximate used to 100-500 mm	1 ~ 500 kHz wideband	And output Small
The thickness Small sensor 24 mm diameter (vibration surface) × L67 mm 	Thickness measurement It applies to approximately 40 to 150 mm: thickness	1 ~ 500 kHz wideband	And output Small

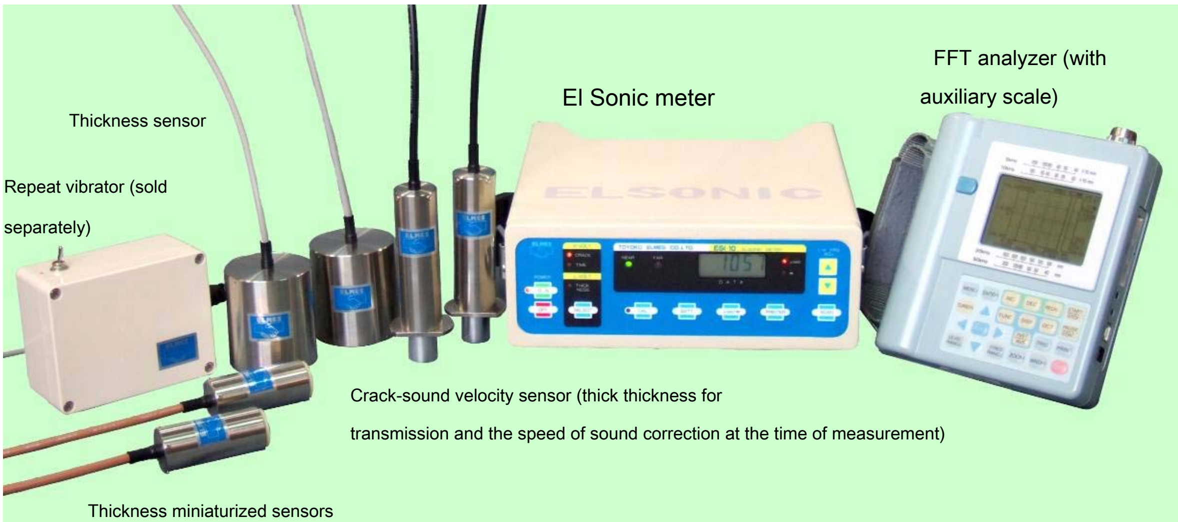
10-3 equipment configuration

Set name [type] / Measurement item	Constitution	product name	Type formula	Accessory, etc.	quantity
El Sonic [ESI / P-10] Crack depth measurement Speed of sound measurement	Standard configuration GOODS	El Sonic meter	ESI-10	Instruction Manual	One
		Crack-sound velocity sensor	ESP-10	transmission and reception	A pair
		AC adapter			One
		Case, measurement equipment		Case, RS-232C cross cable Le, sample program CD, L Form relay connector (BNC, N) each 1 month, AA alkaline batteries 8 This couplant (grease), Bra Shi, scraper, Orishaku	1 set
	Sold separately GOODS	Cracked compact sensor	ESP-11	transmission and reception	A pair
		Cracking powerful sensor	ESP-12	transmission only	One
		Printing printer	DP-1VR	El Sonic for communication cable, AC adapter, the recording paper, handling Manual, quick reference, vinegar trap	1 set
		oscilloscope		BNC 2 cables	1 set
		Test bars (for the speed of sound contrasts)		Made of acrylic	One
		Test piece (simulated cracks)		Made of concrete	One
		External power supply	SG-1000	El sonic power cable, Car (12V) charge for the code, home Use charging adapter, portable cane Ruda bag	1 set
		Sensor for the extension cable		BNC or N-type connector with a	One
		Foot switch			One
El Sonic SP [ESI / P-10S] Crack depth measurement Speed of sound measurement + Thickness measurement	Standard configuration GOODS	El Sonic (set name)	ESI / P-10		1 set
		Thickness sensor	ESP-15	transmission and reception	A pair
		Thickness small sensor	ESP-16	transmission and reception	A pair
		FFT analyzer	SA-78	BNC cable, AC adapter Over, single 2 alkaline batteries, 2ch input conversion adapter, con Compact Flash, storage case, Simple instruction manual, CD-ROM Edition manual (data monitor the Soviet Union With shift)	1 set
	Sold separately GOODS	Printer (for FFT)	DPU-414	RS-232C straight cable, AC adapter, battery pack Click, recording paper, instruction manual	1 set
		Repeat vibrator	ESP-20	transmission only	One

※ In the above table, it is that there is no quantity given after shipped product name, is all Quantity 1.

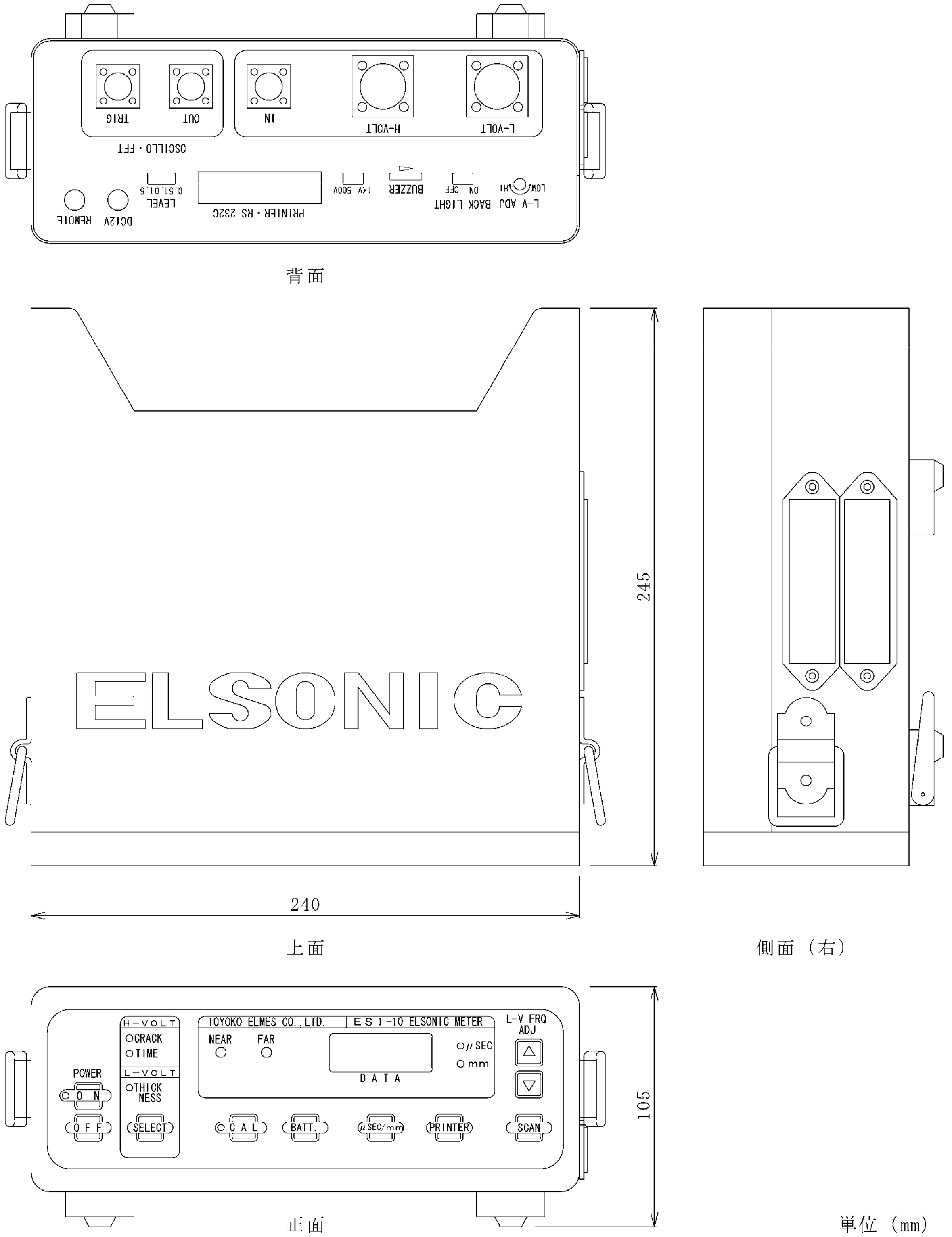
Crack depth, set the speed of sound measurement (El Sonic: ESI / P - Ten)

Crack depth, speed of sound, a set of thickness measurement (El Sonic SP : ESI / P - 10S)

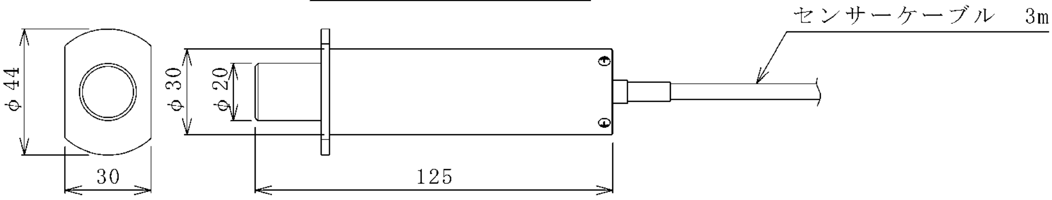


10-4 Dimensions

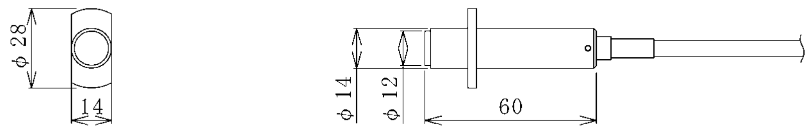
エルソニックメーター



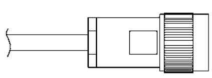
ひび割れ・音速センサー



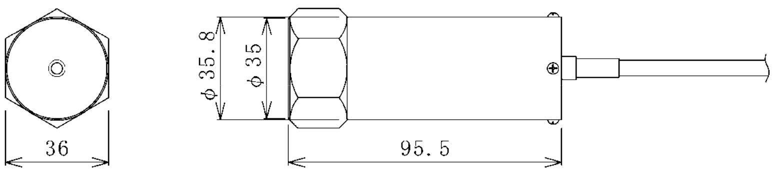
ひび割れ小型センサー



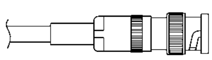
送信側コネクター（N型）



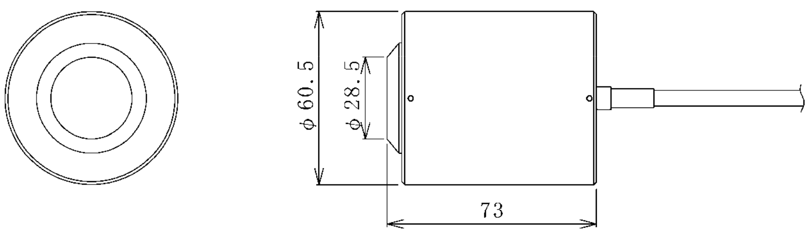
ひび割れ強力センサー



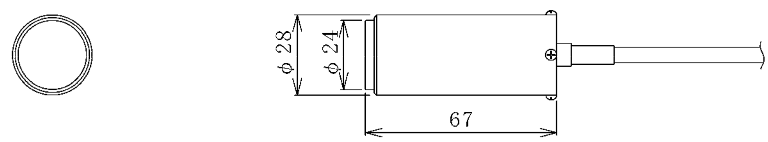
受信側コネクター（BNC型）



厚さセンサー

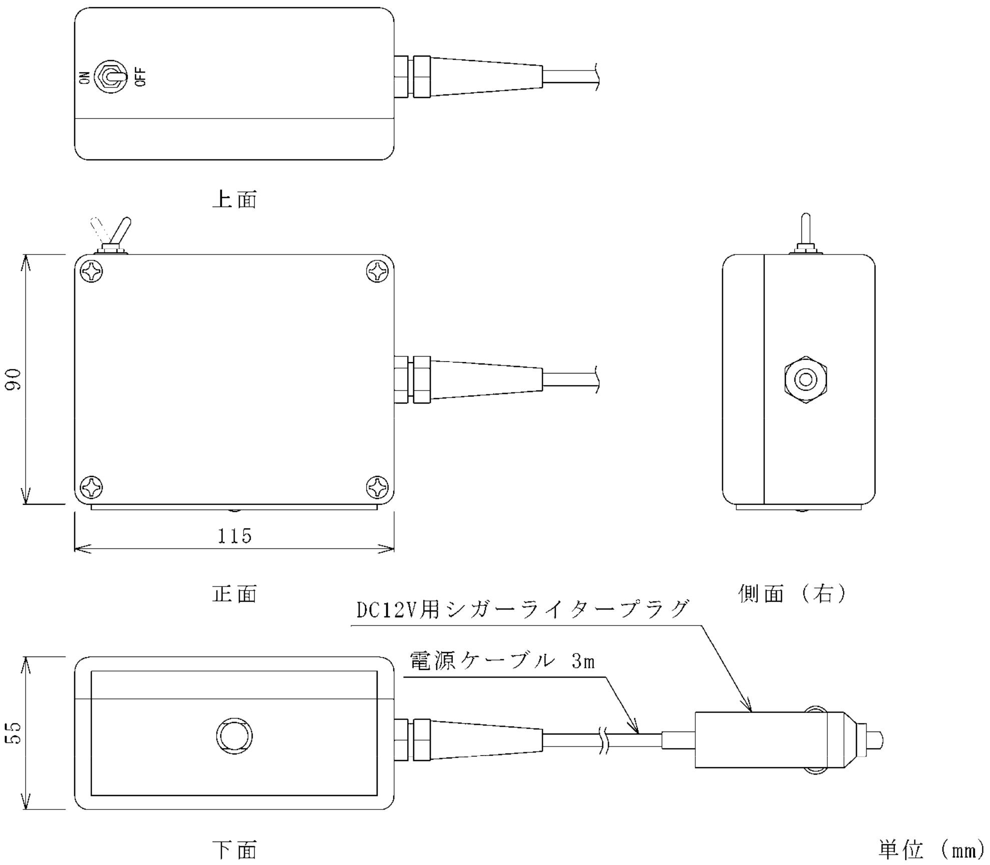


厚さ小型センサー

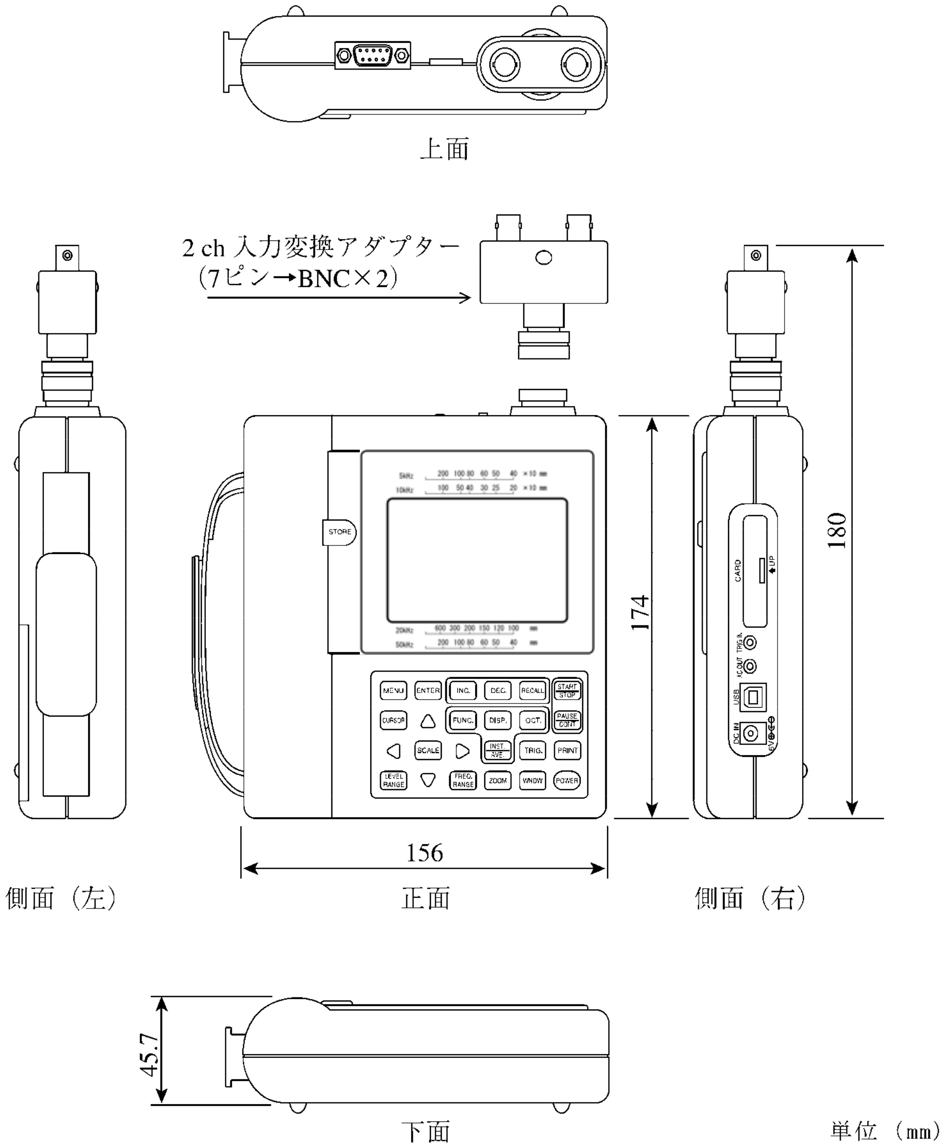


単位（mm）

繰り返し加振器



FFTアナライザー


上面
2 ch 入力変換アダプター
（7ピン→BNC×2）
STORE
MENU
ENTER
INC.
DEC.
RECALL
START STOP
CURSOR
FUNC.
DISP.
OCT.
PAUSE CONT
SCALE
TRIG.
PRINT
ZOOM
POWER
CARD
180
174
156
側面（左）
正面
側面（右）
45.7
下面
単位（mm）

Appendix -1 maintenance

(1) inspection time

Maintains performance of El Sonic, always in order to use in a stable state, it is recommended that you implement the following inspection. ① normal inspection

During the start-up inspection: carried out to work after 5 minutes ago.

Working in check: when necessary, such as during the movement of the measurement location. After work inspection: After the work is completed, promptly perform. ② special inspection

Periodic inspection: carried out once a year.

Extraordinary inspection: When you make the repair and replacement of parts of the device, performed when other necessary.

(2) inspection content, method

① normal inspection

- performs a power supply voltage check, to make sure that the prescribed voltage or more. · Crack depth, connected to the ... transmission and reception sensor case of the speed of sound measurement, to confirm the CAL value. • For thickness measurement connect ... transmitting receiving sensor, no load spectra (see below memo column) to confirm.

No-load spectrum

【Overview】

In THICKNESS mode, referred to as no-load spectrum the spectrum when brought into contact with face-to-face the sensor with each other.

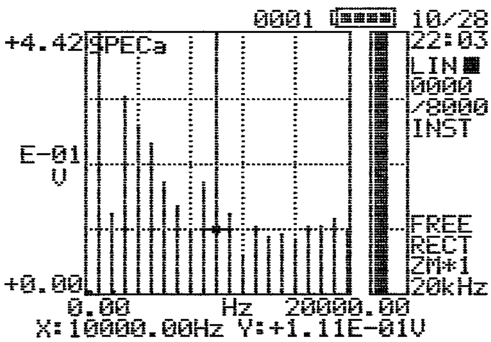
By confirming this spectrum, confirmation that the pulse signal from the El Sonic meter transmission Sensor, receiving sensor, receiver El Sonic meter, and are transmitted normally until FFT, frequency analysis results are displayed correctly I can.

【procedure】

- in accordance with the procedure for thickness measurement, connect the equipment, turn on the power, and the THICKNESS mode.

Thickness sensor (or thickness smaller sensor) like the CAL, apply a small amount of couplant to the center of the tip of the sensor, and those have lightly straight are opposed to the sensor with each other on the floor or desk.

· Please make sure that you have appeared spectrum of 1kHz pitch, such as the right to FFT screen.



※ this operation, please be performed to set the FFT of LEVEL RANGE to + 20dB.

② special inspection

- national standard and using traceability balanced instrument, to calibrate the instrument. • The fabricated concrete test body to measure for each measurement item.

Make sure the provisions of the performance can be obtained by the above, issue the inspection report cards, calibration certificate and traceability system chart.

Cost, please contact the dealer or us for delivery time.

(3) abnormal at the time of treatment

Abnormalities are observed equipment inspection, please do not use.

In addition, when an anomaly is found in and closing time during the work, the measurement data of the inspection just before, please not use.

Refer to the Troubleshooting appendix -3, will check the availability, please contact us if this does not solve the problem to the dealer or the Company.

Change of Appendix -2 hold-off time

(1) the intended use

In such reflection time measurement in water, such as for residual wave, it may digital measurement difficult.

In El Sonic, with respect to this problem, you can respond by changing the hold-off time (time to ignore the input signal).

(2) How to change

Because adjusted with the internal El Sonic meter, please contact us.

Appendix -3 Troubleshooting

We recommend checking the following, in the case of symptoms that do not fit in the case and following poor condition be subjected to treatment, please contact your dealer or our company.

Contents	Cause	Remedy
can not turn on	Plug failure of the AC adapter body	Please re-plug.
	Consumption of batteries	A power supply voltage to confirm, if less than or equal to 10.8V, please replace the battery. Crack depth and speed of sound measurements are sure to use the AC adapter or an external power supply.
Can not be measured (General)	Misuse of the sensor	Please make sure you are using the sensor adapted to the measurement.
	Please connect to the connector connection destination of error correct connector to connect to. Error of	
	measurement mode	Please select the correct measurement mode.
	Breaking sound velocity measurements of sensor cable, in the case of crack depth measurement	Connect the transmission and reception sensor, please check the CAL value. In the case of thickness measurement Connect the transmission and reception sensors, please make sure no-load spectrum.
	Contact medium shortage	Please be fully used.
	Unevenness of the measurement surface	Please be polished with a grindstone.
	Mixed into the sand grains in the contact medium	Wipe the contact medium, please try again.
	How to apply the sensor	Sai that go against the sensor to the measurement surface at a constant pressure.
	Please in close contact in parallel with the inclination measuring surface of the sensor vibration surface.	
	Consumption of batteries	A power supply voltage to confirm, if less than or equal to 10.8V, please replace the battery. Crack depth and speed of sound measurements are sure to use the AC adapter or an external power supply.
	Ambient noise, external noise such as vibration	Noise, or stop the vibration, please by shifting the time. If this is not possible, Sai that go off the reception sensitivity. (0.5 → 1.0,1.5)
You can not crack depth measurement	Contact in the crack plane (iron muscles, clogging of the surface, etc.)	Please measure in the lamp method.
It can not thickness measurement	Ambient noise, external noise such as vibration	Noise, or stop the vibration, please by shifting the time. Or please perform the averaging calculation of the FFT.
	It is not that the floor panel contains a large number of cracks	Please measure over a wide surface. Please do not measured in the vicinity of the seams and cracks.
	Close to the end of the floor panel	Thickness 3 times or more, please measured at the end instead of or midway, measured at a distance from the end.

Contents	Cause	Remedy
CAL value is different from the normal ± 0.3μs within	There is no abnormality	It performs the CAL operation (without having in hand) in the state where placed on the floor or desk, when combined usually to the same value as, if the display is stable and without Furatsuka, no abnormality is or. Why the values are different, is first amount of time of digital conversion Coca error ± 0.1 .mu.s, and because there may vary by ± 0.1 .mu.s by differences in the thickness of the coupling medium interposed between the sensor (grease).
CAL value is less unusual 1μs more ※ cracking small type sensor other than	Electrical noise between the transmission and reception sensor	The plane of vibration of-receiving sensor sent, in a state sandwiched between the contact medium (insulator), please together lightly. When the pressing too strongly, vibration face each other in direct contact, becomes transmission (electrical) signal and noise to the receiving sensor, a shorter time than the normal CAL value it will be displayed. In addition, while the receive your long, scratched in the vibration surface in contact touch with the concrete surface, there is a case where the insulating due to the contact medium is difficult than the original. In that case is a thin cellophane tape or the like may be sandwiched in the vibrating surface.
CAL value is large change, stable display and have such and unsteady.	Please contact the disconnection of purchase or our sensor cable	

Appendix -4 Glossary

This section describes the terms used in the text. Mainly we quote the JIS Z 2300, JIS Z 8106.

	the term	Theory Akira
Ah	The ratio of the sound pressure to the cross-sectional area and the sound velocity of the product of the medium given acoustic impedance.	Usually expressed as the product of sound velocity and density.
	Speed of sound	Group velocity or phase velocity of the sound with respect to the propagation direction of the homogeneous medium. In this paper, it represents the mainly that of the speed of the ultrasonic wave transmitted through the concrete.
Or	Diffracted wave	Sound, light, radio waves, in any of the waves, such as waves of water, the waves in the obstacle of the wavelength and the same degree of size in addition to straight, there is a property that goes around to the shadow. Refers to this around write Minonami and the diffracted wave, unlike a gas or a liquid or radio waves, solid door-out of the acoustic wave, the wave will cause the diffraction phenomenon in which certain features.
	Head	The shortest distance between the rebar surface and the outside of the concrete surface. Head thickness also am saying.
	CAL operation	CAL value (P.15 see) is the zero reset to operate. It stands for CALibration. Commonly known as CAL (CAL).
	Decay	When sound waves propagating in the medium, the decrease in sound pressure caused by absorption and scattering.
	The nominal frequency	Frequency, which is displayed on the sensor. It does not guarantee that the same frequency as the nominal frequency propagating the concrete over the door.
	Wideband sensor (probe)	1 wave or a sensor that generates a very short ultrasonic pulses of about 2 waves (feeler element).
	Directivity	Spatially properties ultrasound propagates biased in one direction. It is in the concrete low frequency of ultrasound, also because immediately wavelength attenuation is increased, the directivity is bad.
	frequency	The reciprocal of the period of the vibration. Number of repeats per second. Unit "Hertz" (Hz) is used.
	Vibrator	Converting electrical energy into acoustic energy, or active elements vice versa. Such as a piezoelectric ceramics will be used.
	Janka	Often heterogeneous portion of only coarse aggregate in a portion of the cured concrete were Deki gathered gap.
	Reception sensitivity setting switch	It called the threshold and Threshold values, switching between the in converting the received voltage into a digital value, to recognize the "1" in much more switches.
	Spectral	Decomposing complex wave viewed on a time axis for each frequency component, and base parallel to the ascending order of frequency, the overall plight of showing components of the magnitude of each frequency. Spectral distribution diagram.
	Contact medium	Such as water and glycerin, the medium to be inserted between the probe and the specimen to allow ultrasonic energy transmission therebetween. Acoustic coupling medium.
	To perform transmission and reception of the sensor (probe) ultrasound, incorporating one or more vibrators	Dale electro - acoustic transducer. Since there is no familiar ultrasonic probe, including the English of the probe as the site terms in El Sonic, it uses a sensor. AE sensor is the official language, the ultrasonic sensor is idioms.

	the term	Solutions Theory
It was	Comparison test pieces	Specimens fabricated as purpose of speed-of-sound measurement of the ultrasonic instrument.
	longitudinal wave	Mode propagation direction same wave vibration and the vibration direction of the medium particles. In the solid, the fastest speed of sound.
	Acoustic wave	Elastic vibration transmitted through the elastic body. Such as sound waves, seismic waves.
	Ultrasonic	High frequency of the sound waves inaudible to the human ear. Frequency to say the least of the sound wave 16kHz in a narrow sense, in a broad sense refers to the sound waves which are not intended to be heard 16kHz even the human ear is directly below.
	Propagation time	Time to the transmitted ultrasonic wave reaches the receiving point. Time ultrasound propagates through the test specimen in a sensor, reaches the sensor.
It is	pulse	Signal to continue only a very short time.
	FFT analyzer fast Fourier transform spectrometer. Fourier	
	analysis	How to analyze complex wave as the synthesis of simple trigonometric wave seen in the time axis. It shows a spectrum arranging the magnitude of each frequency component in ascending order of frequency.
	BNC cable	Coaxial cable with BNC-type connector
	Mechanism Ho to ignore received even if a certain time signal from the time that the hold-off time	Rudoofu. Says the time.

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